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Why has the Norwegian krone exchange rate been persistently weak? A fully simultaneous VAR approach

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Abstract:
We identify variables that help explain the persistent weakness of the Norwegian krone since 2016 within a fully simultaneous model of the underlying process driving the krone-euro exchange rate. In addition to a set of fundamental variables we consider non-traditional explanatory variables related to an exchange rate premium, inspired by several claims to insights made by market participants. The weak Norwegian krone seems to be largely attributable to factors related to the risk premium, such as the declining importance of petroleum in the Norwegian economy, a relative reduction in FDI in Norway and a fall in oil industry-specic share prices.

Keywords: Exchange rate, Foreign exchange rate premium, Cointegration, VAR-analysis.

JEL classification: C22, C32, F31,F41,G15

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Sammendrag

Etter at inflasjonsmålet formelt ble innført i Norge i 2001, er det tre perioder som skiller seg ut med en klar svekkelse av den norske kronen: fra rundt 2001, 2008 og 2013. Fra de to første kom kronekursen raskt tilbake, men fra den tredje har den ikke styrket seg igjen. Siden 2016 har utviklingen i euro-kronekursen (NOKEUR) ikke vært i tråd med fundamentale forhold og oljeprisen. Denne artikkelen undersøker hvilke faktorer som kan ha forårsaket den forlengede perioden med en svak krone.

Vår modell for kronekursen tar utgangspunkt i de to klassiske hypotesene om kjøpekraftsparitet (PPP) og udekket renteparitet (UIP), eller snarere avvik fra UIP i form av en valutarisikopremie. For å kunne fange opp eksistensen av en valutarisikopremie, inkluderer vi en rekke tilleggsvariabler i informasjonssettet. For det første inkluderer vi verdien av norsk olje- og gasseksport som andel av total norsk eksport, som en indikator på oljesektorens viktighet for norsk økonomi. For å fange opp effektene av ulike typer investoradferd, inkludert forventninger om et grønt skifte, økt fokus på investeringer som tar hensyn til miljø-, sosiale- og forretningsetiske forhold og markedssentiment, har vi, i tillegg til flere usikkerhets- og volatilitetsindekser, også inkludert en bransjespesifikk oljeaksjeindeks og differansen mellom utenlandske direkteinvesteringer rettet mot euroområdet og Norge i prosent av BNP. Vi åpner også for effekter av oljeprisen.

Vi identifiserer en velspesifisert modell for NOKEUR, som gir støtte for en teoretisk modell basert på avvik fra UIP, tolket som en valutakursrisikopremie. På lang sikt er dermed kronekursen avhengig av relative priser og realrentedifferansen overfor euroområdet, samt en rekke variabler som kan antas å representere en valutarisikopremie. Disse inkluderer en variabel som skal representere den relative betydningen av olje og gass i norsk økonomi, men også variabler som er ment å fange opp effektene av investoradferd mer direkte, som differansen mellom utenlandske direkte investeringers (UDI) andel av BNP i Norge og eurolandene, samt en bransjespesifikk aksjeprisindeks knyttet til produksjon av olje og gass i Norge. I tillegg finner vi mer direkte støtte for trygg havn – atferd, som gjenspeiles av en betydelig effekt av endringer i volatiliteten til den amerikanske S&P-aksjeindeksen (VIX). På kort sikt er kronekursen i stor grad drevet av endringer i oljeprisen og renter, i tillegg til egendynamikk. Med unntak av VIX-indeksen og i motsetning til det som gjelder på lang sikt, ser effekten av disse tilleggsvariablene først og fremst ut til å være gyldige først fra 2016.

Den svake norske kronen de senere årene ser i stor grad ut til å kunne tilskrives faktorer relatert til risikopremien, som avtagende betydning av olje og gass i norsk økonomi, en relativ reduksjon av UDI i Norge og et fall i den bransjespesifikke aksjeprisindeksen knyttet til olje- og gassproduksjon i Norge. Langsiktstrukturen i modellen indikerer at disse faktorene i stor grad drives av oljeprisen på lang sikt.

1 Introduction

After inflation targeting was formally introduced in Norway in 2001, there are three periods that stand out with a marked weakening of the krone exchange rate (NOK). From the first two, it quickly regained its strength, but from the third, it has not recovered to this very day.

In 2001-2002, the krone strengthened markedly, which can probably largely be attributed to an increased interest rate differential between Norway and other countries, cf. for example Naug (2003). The following weakening probably overshot, after which the NOK rapidly reverted to around its previous level, and more in line with a closing of the interest rate differential.

While the international financial crisis was in the acute phase in the autumn of 2008, the krone weakened sharply as a result of a flight to large, safe haven currencies such as the US dollar and the Swiss franc, before the krone regained its previous strength through 2009 and into 2010.

It appears that the krone exchange rate had a strong tendency to return to just over NOK 8 for one euro from the late 1980s and throughout the two following decades. However, from 2013 and into 2016, the krone weakened to previously unseen levels against the euro, first due to a general strengthening of the euro which may have been caused by improved prospects for the European economy, but, especially from the summer of 2014, also as a result of the steep fall in oil prices. Since 2016 the development in the NOK has not been in line with fundamentals and the oil price. This paper investigates what factors may have caused the prolonged period of a weak NOK.

In order to understand exchange rate dynamics and to perform efficient macroeconomic policies in a globalized economy, empirical evidence of exchange rate determination is key. Standard economic models hold that exchange rates are influenced by fundamental variables such as output, inflation and interest rates, see e.g. Williamson (2009) for a survey of theoretical literature. From a large number of empirical studies, evidence is mixed, see e.g. Meese and Rogoff (1988), Sarno and Taylor (2003), Sarno (2005), Engel et al. (2007) and Frenkel and Johnson (2013). Nevertheless, many studies have found empirical support for such fundamentals based models. Kurita and James (2022) find evidence that macro economic variables are the core elements determining the Canadian-US dollar exchange rate. Bergvall (2004) investigates the Nordic countries' exchange rates and finds that output growth, trade deficits or improved terms of trade go along with appreciated exchange rates and that exogenous terms-of-trade shocks are the most important determinant of long-run movements in the NOK real exchange rate. Akram (2006) and Drine and Rault (2008) find support for purchasing power parity (PPP) for Norway and a number of OECD countries, respectively. Koijen and Yogo (2020) find that macroeconomic and policy variables explain more than 50 percent of the exchange rate variation. There is also a strand of the literature documenting contemporaneous relationships between exchange rates and financial variables, where e.g. Engel and Wu (2018), Valchev (2020) and Jiang et al. (2021) find evidence for a link between exchange rates and convenience yields, and Lilley et al. (2019) and Stavrakeva and Tang (2020) find a relationship between cross-border asset holdings or derivatives positions and exchange rates. Another strand connects exchange rate and currency premia to macroeconomic fundamentals, see e.g. Gourinchas and Rey (2022) and Stavrakeva and Tang (2019).

In our model for the NOK-Euro exchange rate,[1] we take as our starting point the classical hypotheses of purchasing power parity (PPP) and uncovered interest parity (UIP) or rather deviations from UIP, the latter in terms of a foreign exchange risk premium, see for example Johansen and Juselius (1992), Miyakoshi (2003), Juselius and MacDonald (2006), Rashid (2009), Avdjiev et al. (2019), Stavrakeva and Tang (2019) and Stavrakeva and Tang (2020). Like Akram (2006), Bjørnland and Hungnes (2006) and Bjørnstad and Jansen (2007), we are open to effects of oil prices on the NOK exchange rate. Reboredo (2012) investigates the comovement of exchange rates and oil prices and emphasizes how an oil price shock transmits to financial markets and the real economy through the USD exchange rate. Nusair and Kisswani (2015) find oil prices to be of significance for several Asian exchange rates, and Kurita and James (2022) find evidence that oil prices are important for the short-term dynamics of the Canadian-US dollar exchange rate.

However, in order to better capture the existence of an exchange rate premium and in this context also to take into account potential effects related to market dynamics and microstructure, we include a number of additional variables in our information set, inspired by several claims to insights made by market participants. First, we include the value of Norwegian oil and gas exports as a share of total Norwegian exports as an indicator of the importance of the petroleum sector to the Norwegian economy. To capture the effects of different types of investor behavior including expectations of an imminent green shift, increased focus on ESG-related investments[2] and market sentiment, we have included an industry-specific oil equity index and the difference between foreign direct investments in the euro area and Norway, both as a percentage of GDP. Finally, we have also included indices

[1]The euro is by far the most important currency for Norwegian trade. In 2020, close to 35 per cent of Norwegian exports of traditional goods and services went to the euro area.

[2]ESG (Environmental, Social and Governance) investing refers to a class of investment that is also known as "sustainable investing." This is an umbrella term for investments seeking positive returns and long-term impact on society, environment and the performance of business.

reflecting uncertainty and volatility, like for instance a couple of area specific uncertainty indices[3] and the S&P500 VIX index.

The VAR pertaining to the long-run cointegration analysis is estimated by utilizing the probability maximization method (full information maximum likelihood, hereinafter referred to as FIML) while the design and estimation of the dynamic contingent krone-euro specification has been undertaken by resorting to a combination of an automatic model reduction scheme and hands-on design utilizing a single equation ordinary least squares (OLS) procedure.[4] We use quarterly data, and the estimation period runs from the time when an inflation target was introduced in Norway in 2001, to 2020.

We identify a well-specified model for the NOK-Euro exchange rate, providing support for a theoretical model based on the deviation from UIP, as represented by the existence of a foreign exchange rate risk premium. Hence, in the long run, the krone exchange rate depends on relative prices and the real interest rate differential vis-à-vis the euro area, as well as a number of variables that may be taken to represent a foreign exchange risk premium. These include a variable that is intended to capture the relative importance of oil and gas in the Norwegian economy, but also variables that are intended to capture the effects of investor behavior more directly, i.e. the difference between foreign direct investments directed towards the euro area and Norway as a share of GDP as well as an industry-specific share price index related to the production of oil and gas in Norway. In addition, we do find more direct evidence of safe-haven behavior, as reflected by a significant effect of changes to the volatility of the US S&P equity index (VIX).

In the short term, the krone exchange rate is to a large degree driven by changes to the oil price and interest rates, although some additional variables related to the risk premium and eigen dynamics are found to be significant as well. However, with the exception of the VIX and in contrast to what applies to the long term, the effect of these additional variables primarily appears to be valid only from 2016 onwards. We do also identify a seasonal weakening of the NOK due to a thin NOK market in the last quarter of each year.

The weak krone over the last four to five years seems to stem from factors related to the risk premium, such as the declining importance of oil and gas in the Norwegian economy, but also by negative developments in variables that are intended to capture the effects of investor behaviour more directly, such as a reduction in the relative flow of inward FDI-investments in Norway versus the euro area, and a fall in the industry-specific share price index related to oil and gas production in Norway. The long-term structure of the model indicates that

[3]These uncertainty indices are taken from the Fred data base and include a world uncertainty index, a world trade uncertainty index and an uncertainty index pertaining to advanced economies and the Western Hemisphere.

[4]Doornik (2016).

these factors are largely driven by oil prices in the long run.

The theoretical background is explained in Section 2, where we briefly explain the key concepts of international purchasing power parity, uncovered interest rate parity and rational expectations, and argue for including variables that capture a foreign exchange premium as explanatory variables in the empirical analysis. Section 3 presents data and identifies possible long-term relationships between a set of different variables in our information set. Finally, Section 4 presents the results of the empirical analysis, including simulations aimed at illustrating the model's in-sample prediction and ex ante forecast properties. Section 5 summarizes and concludes.

2 Theoretical background

The hypothesis of purchasing power parity (PPP) in its most restrictive form is based on the law of one price, which states that (in the long run, or in equilibrium) the cost of a commodity or a commodity group is the same regardless of which currency (or country) you buy it in, see for example Sarno and Taylor (2002).[5] Then the bilateral exchange rate between two countries can be expressed as the relative price ratio between the two countries,

$$S_t = P_t/P_t^*, \tag{1}$$

where S is the nominal, bilateral exchange rate, and P_t and P_t^* are the price levels in the two countries in period t. Let us for the sake of simplicity call them home and abroad, respectively, where the latter is marked with an asterisk (*). PPP must be considered as an equilibrium, and thus (1) as an equilibrium condition. In practice, there will be deviations from PPP for a number of reasons. There may be data problems, such as a weak connection between the price measures used, typically the consumer price index (CPI), and the price you actually want to measure. There may also be more fundamental factors, such as the existence of shielded goods and services, trade barriers, price movements driven by speculation, differences in productivity, long-term fiscal imbalances, long cycles in commodity prices and interest rate differentials, which we will return to shortly.

If we multiply by P_t^*/P_t on both sides in (1) and take the logarithm, we get that $q_t = s_t + p_t^* - p_t = 0$ in equilibrium, where Q is the real exchange rate and lower case letters indicate logarithmic form. This equation may equivalently be written as

[5]An extension of the PPP hypothesis, known as *relative* PPP, relates changes in (expected) inflation in two countries to (expected) changes in the bilateral exchange rate. This implies that the prices (of the same product) may be different in different countries, but that the price difference is (or varies around a) constant over time. The real exchange rate must be stationary for PPP to hold in the long term.

$$q_t = s_t - p_t + p_t^*. \tag{2}$$

As we see from (2), the real exchange rate can be interpreted as a deviation from PPP. There is little empirical support for PPP in the short term, but employing long time series there are several studies that find support for it in the long term. Fair (2004) finds support for PPP for 8 out of 22 countries with time series of more than 50 years in his global macro econometric model. Akram (2006) finds support for PPP between Norway and its trading partners using long time series. Uncovered interest parity (UIP) states that the interest rate differential between two countries shall be equal to the expected change in the bilateral exchange rate between the countries, and can be expressed by

$$E_t \Delta s_{t,T} = I_{t,T} - I_{t,T}^*, \tag{3}$$

where E_t is the expectation operator, $E_t \Delta s_{t,T} \equiv E_t s_T - s_t$ is the expected (at time t) percentage change in the exchange rate in the period from time t to T and $I_{t,T}$ and $I_{t,T}^*$ are the nominal interest rates at home and abroad on deposits or securities with a maturity equal to $T - t$. UIP applies in an efficient market, and then it does not matter for the return in which country one invests money in interest-bearing securities, since an interest rate difference between two countries will correspond to an opposing change in the bilateral exchange rate in the same period. The hypothesis of efficient markets is consistent with risk-neutral market participants (on average) with rational expectations, see e.g. Sarno (2005).

If we express UIP in real terms and allow for a risk premium, z_t, (3) can be rewritten as

$$q_t = E_t q_T - (E_t R_{t,T} - E_t R_{t,T}^*) + z_t, \tag{4}$$

where $E_t q_T$ is the expected real exchange rate in period T, $E_t R_{t,T} = I_{t,T} - [E_t p_T - p_t]$ is the ex ante expected real interest rate and $E_t p_T - p_t$ is expected domestic inflation in the period t to T. $E_t R_{t,T}^*$ is the corresponding expected real interest rate abroad.

If we combine PPP and UIP, represented by Equations (1) and (4), respectively, by inserting for q_t, we get

$$s_t = p_t - p_t^* + E_t q_T - (E_t R_{t,T} - E_t R_{t,T}^*) + z_t. \tag{5}$$

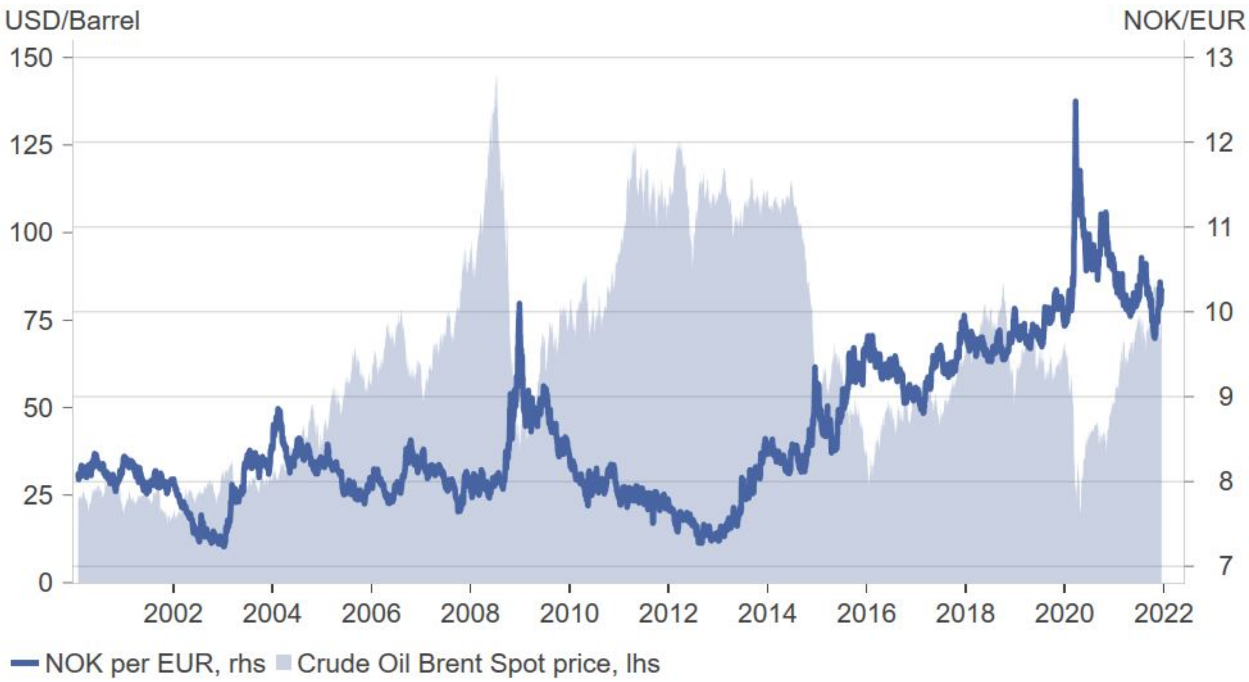
According to (5), the nominal exchange rate is determined by the current relative prices between the two countries, the expected long-term real exchange rate and the expected future real interest rate differential plus a risk premium. This equation forms the basis for our empirical analysis, in which we also try to capture the effect of a risk premium via the use of a number of indicators, as explained in Section 4.

3 Data

The exchange rate relationship is estimated on quarterly data. The estimation period runs from 2001, when an inflation target for monetary policy was first introduced, to 2020.

As in most oil-exporting countries, there is reason to believe that the oil price is important for the exchange rate. Higher oil prices and revenues can contribute to real appreciation pressure (and vice versa) which (in part) translates into the nominal exchange rate, see for example Benedictow et al. (2013). Akram and Mumtaz (2016) find an increasing correlation between oil prices and nominal exchange rates in the Norwegian economy, especially since around the turn of the millennium. This must be seen in connection with the introduction of the rule for the Petroleum Fund (Government Pension Fund Global) and rising oil prices beyond the 2000s, which led to the fund rapidly increasing in size.

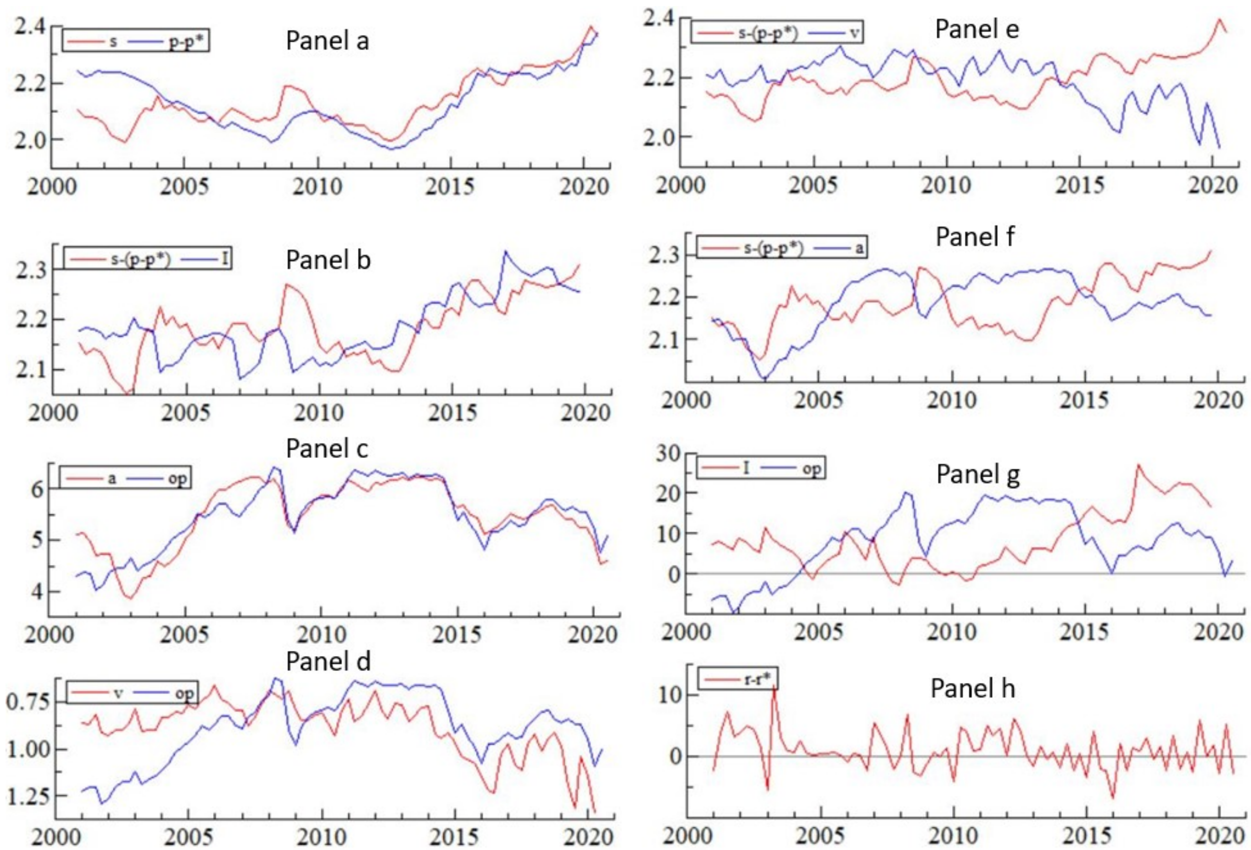
Figure 1: NOK per Euro and the oil price per barrel in USD



Source: Macrobond

Figure 1 shows that the krone euro exchange rate looks fairly stable at just over NOK 8 for large parts of the estimation period, at least until 2014 when it began to weaken considerably, partly as a result of sharply falling oil prices.

Figure 2: Data



Source: Norges Bank, Macrobond, Statistics Norway

Figure 2 depicts simple bi-variate correlation patterns between some of the most important variables in our information set, where the variables have been scaled to match by means and ranges. First, panel a indicates a strong relationship between the logarithm of the nominal NOK-Euro exchange rate, s, and the nominal price differential between Norway and the euro area, $p - p^*$, a relationship that seems to be particularly pertinent from 2014 onwards when the krone started to weaken in earnest. However, looking at panel b, which depicts the real exchange rate, q, together with the value share of oil and gas in total exports, v, this relationship does not seem to be one-to-one in the sense of generating a stationary real exchange rate. Thus, this opens up for the possibility of other variables informing the real exchange rate in the long run, a key candidate in that respect – and as born out by the same panel – being the above mentioned value share of oil and gas exports. However, the two subsequent panels of the same figure, panel c and panel d, introduces two other candidates in this respect, respectively, an energy-specific share price index, a, and the development in the accumulated net capital flow as a share of GDP between EMU and Norway, I. Both variables demonstrate some capacity in capturing certain aspects of the non-stationary nature of the real exchange rate. Figure 2 also demonstrates the Norwegian economy's degree of oil dependence more in general as all the variables mentioned above seem to be highly connected to the US dollar price of oil, *op*, in one way or another. This applies not only to the value share of oil and gas of total exports, as born out by panel e, but also to the energy related share price index, (a), and the variable representing the expansion in the net capital position between Norway and the countries of the euro area. The last panel, h, shows the real interest rate differential between Norway and the euro area, $r - r^*$, and clearly demonstrates its high degree of stationarity, a stylized fact that will later form the basis of the co-integration analysis to come.

Furthermore, our analysis is conditional on indices reflecting uncertainty: the S&P volatility index (VIX) and a couple of world uncertainty indices from the FRED database.[6]

4 Econometric Analysis

We have chosen as a point of departure the equilbrium correction version of the vector autoregressive model written in reduced form. In the general case this can be given the following representation:

$$\Delta X_t = \Pi Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Phi D_t + \epsilon_t, \tag{6}$$

where X_t represents a $p \times 1$ vector of endogenous variables, $Y_t = (X_t', Z_t')'$ a $(p+q) \times 1$ vector where Z_t is a $q \times 1$ vector of exogenous variables and k the order of the VAR. D_t is a vector composed of contemporaneous and lagged differences of the model's exogenous variables, Z_t, deterministic variables like dummies,[7] a trend and a constant. ϵ_t is a Gaussian white noise vector with an unrestricted covariance matrix Ω. The rank of the Π matrix gives us information about the cointegration properties of the model, and in the case the rank, r, is less than full, i.e. less than p, the Π matrix may be written as the product of a $p \times r$ matrix, α, and a $(p+q) \times r$ matrix, β, with full column rank equal to $r < p$. The level term in Equation (6) can then be written as $\Pi Y_{t-1} = \alpha\beta' Y_{t-1}$ where $\beta' Y_{t-1}$ represents the r cointegrating linear combinations of the variables while the α matrix has got the interpretation of a coefficient matrix with equilibrium correction coefficients or loadings.

[6]As non of these world uncertainty indices turned to be significantly estimated in the analysis we have in the following chosen not to comment on these, referring the interested reader to the FRED web page for more information: $https://fred.stlouisfed.org/$.

[7]Including seasonal dummies.

The cointegration analysis in connection with the preparation of the "structural" equilibrium correction model of the Norwegian euro krone exchange rate[8] is based on a five dimensional conditional VAR of order 3, for the simultaneous determination of, respectively, the real exchange rate, q,[9] the real interest rate differential vis-à-vis the euro area, $\tilde{r} = r\text{-}r^*$, an equity index covering the Norwegian market for oil services and machinery, a, the ratio of the value of oil and gas exports to the total value of Norwegian exports, v, and the difference between foreign direct investments as a percentage of GDP in the euro area and Norway, I. In addition to a constant and some dummies for structural breaks the model is contingent on the Brent blend crude oil price in US dollar, *op*, and the S&P volatility index, VIX, being exogenous processes.

4.1 Long-run Analysis

Starting out with the reduced form analysis and the identification of the model's long-run structure, the results, as reproduced in Table 1 and Table 2, give unambiguous and strong support for the existence of no less than five cointegrating vectors.[10] Without going into any great detail, the overidentified structure in the upper part of Table 2 associates a long-run cointegration relationship with each of the individual variables treated as endogenous in our five dimensional VAR. In particular, the first two cointegrating relationships pertain to, respectively, the real krone euro exchange rate and the real interest rate differential, the last of them implying that the variable constitutes a stationary relationship in itself. The three other relationships can be said to represent the degree of dependency on oil of the Norwegian economy, as measured by, respectively, two different kinds of investor behaviour and the relative contribution of oil and gas exports to the total value of exports in Norway. As for the long-term krone-euro exchange rate equation, it provides support for several hypotheses that could potentially help shed light on recent developments. To a varying degree all of them may be related to the behaviour of future-oriented investors both envisaging the possibility of a green shift and prospects for international tensions and unrest. First, according to the first long-run relationship, the real exchange rate will weaken as oil and gas make up a smaller

[8]To distinguish the type of model developed in this paper from a reduced form model we will use the term structural throughout, being fully aware that a more proper term in this context would perhaps have been behavioural or relational, given the lack of a fully structural underpinning of its rationale.

[9]We have chosen to base the cointegration analysis on the presumption of a full pass-through of relative price changes to the nominal exchange rate in the long run. This restriction is given broad support based on preliminary analyses where such a restriction was not imposed a priori, and is later dissolved when we proceed with the dynamic design of our contingent model for the krone-euro exchange rate. This has been done to keep the system's dimension and complexity down to a manageable level.

[10]As is born out by the significance probabilities of the tests for the number of cointegrating vectors they are all significant to a level very close to or substantially below 1 per cent.

share of the Norwegian economy, a one per cent fall in their export share is estimated to lead to a long-term weakening of the krone-euro exchange rate of approximately 0.23 per cent.

Furthermore, a one per cent fall in the industry-specific share price index of the oil sector will also lead to a real exchange rate depreciation, though the effect is estimated to be rather weak.

However, combined with a potential outflow of capital, represented by the difference between foreign direct investments as a percentage of GDP in the euro area and Norway, and the S&P volatility index denoted VIX, it is no denying that these effects taken together would contribute to mount a persistent negative long-term pressure on the krone-euro exchange rate in the absence of countervailing forces.[11]

Moreover, the F-test for the number of over-identifying restrictions in Table 2, shows that the identified system, consisting of five cointegrating relationships, constitutes a valid restriction of a corresponding exactly identified long-run structure.[12]

[11] The VAR of order 3 amounts to a valid reduction of a data congruent VAR of a higher order. With the exception of a normality deviation in the foreign direct investment equation due to a structural break in the first quarter of 2017, which we deliberately have chosen not to allow for, none of the individual equation hypotheses for normality or absence of residual autocorrelation and heteroscedasticity are in this model rejected at conventional significance levels. The system diagnostics of the VAR(3) model, given below, where the figures in square brackets are the respective tests' significance probabilities, do neither give rise to any concern.

Vector AR 1-5 test:	$F(125, 98)$	=	1.0771[0.3519]
Vector Normality test:	$\chi^2(10)$	=	15.4444[0.1167]
Vector Heterosc. test:	$F(260, 95)$	=	0.9689[0.5840]

The F-test statistic for the elimination of all lags greater than 3 from the model is F(63,84)=1.2966[0.1325], where the figure in parenthesis is the test's significance probability. Neither were any of the partial reductions of the model reduction scheme — from a VAR of order 6 down to a VAR of order 3 (and even 2) — rejected.

[12] The value in parenthesis under each estimated coefficient is its standard error while the value in parenthesis following the test of over-identifying restrictions refers to the test's significance probability. Note that the test statistic of over-identifying restrictions refers to the restrictions one will have to impose on an exactly identified long-run structure to arrive at the final structure given by the cointegrated system's over-identified right hand side. In order to exactly identify the system and to generate estimated standard errors for the beta matrix, we had to calibrate the parameter that applies to the (I + VIX) term. This calibration is based on the estimate of this parameter made in the step prior to arrive at the final over-identified structure in Table 2. The variables q_t, v_t, $\tilde{r}_t = (r - r^*)_t$, a_t, I_t and op_t stand for, respectively, the real exchange rate, the ratio of the value of oil and gas to the value of total exports, the real interest rate differential, an equity index pertaining to the Norwegian oil industry, the difference between foreign direct investments as a percentage of GDP in the euro area and Norway, the oil price in US dollars, lower case letters denoting logarithmic transformations of the original variables referred to in the text. r_t^i, where the index i is either a blank or a star, stands for the two real interest rates, neither of which has been transformed logarithmically. The vector to the left of the loading matrix and before the colon refers to the individual equations in the corresponding reduced form VECM representation. As usual the Δ symbol stands for the first difference operator.

Table 1: Johansen's test for the number of cointegrating vectors

VAR order: 3, unrestricted constant, ordinary and seasonal dummies and exogenous variables. Estimation period: 2001Q1 to 2019Q4.

Trace Eigenvalue test:		
H_0	H_1	Values of test statistics
r=0	r $\leq$ 5	130.22[0.000]**
r $\leq$ 1	r $\leq$ 5	106.16[0.000]**
r $\leq$ 2	r $\leq$ 5	62.224[0.001]**
r $\leq$ 3	r $\leq$ 5	38.855[0.003]**
r $\leq$ 4	r $\leq$ 5	19.609[0.010]*(*)

(1) The values in square brackets are the respective tests' significance probabilities.
2) * and ** signify that the test is significant at a level of 5% and 1%, respectively, the star in parentheses after the brackets of the last test statistic indicating that the test's p-value only marginally is above its 1% quartile.

4.2 Dynamic design

Given the long-run structure in the upper part of Table 2 the next step is to specify a general unrestricted conditional "structural" model (GUM) of the krone-euro nominal exchange rate involving in principle all the cointegrating relationships and the variables in the VAR and to reduce it down to a parsimonious representation by resorting to a combination of automatic and manual hands-on model reduction schemes.[13]

The structural form or SEM representation of the reduced form is obtained by multiplying (6) by a contemporary response matrix B. This results in the simultaneous equation system:

$$B\Delta X_t = B\Pi Y_{t-1} + \sum_{i=1}^{k-1} B\Gamma_i \Delta X_{t-i} + B\Phi D_t + B\epsilon_t,$$

or after having set $B\Pi = B\alpha\beta' = \alpha^*\beta'$, $B\Gamma_i = \Gamma_i^*$, $B\Phi = \Phi^*$ and $B\epsilon_t = u_t$

$$B\Delta X_t = \alpha^*\beta' Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i^* \Delta X_{t-i} + \Phi^* D_t + u_t \tag{7}$$

Given the five previously estimated long-run relationships and the fact that the cointegration

[13] In reducing the GUM we have occasionally resorted to utilizing the Autometrics module in Doornik (2015).

Table 2: The identified system of cointegrating linear combinations given r=5, the loading matrix and a test of overidentifying restrictions

The identified long-run structure given 5 cointegrating relations:

$$\hat{\beta}' \begin{pmatrix} Y_t \\ X_t \end{pmatrix} = \begin{pmatrix} q_t + \underset{(0.013)}{0.023}\, a_t + \underset{(0.063)}{0.227}\, v_t - 0.004\,\{I+VIX\}_t \\ \{r-r^*\}_t \\ \{v-op\}_t \\ a_t + \underset{(0.014)}{0.043}\, VIX_t - op_t \\ I_t + \underset{(2.47)}{81.645}\, op_t \end{pmatrix}$$

Equilibrium correction coefficient matrix:

$$\begin{matrix} \Delta q \\ \Delta \tilde{r} \\ \Delta v : \\ \Delta a \\ \Delta I \end{matrix} \begin{pmatrix} \hat{\alpha}_{11} & \hat{\alpha}_{12} & \hat{\alpha}_{13} & \hat{\alpha}_{14} & \hat{\alpha}_{15} \\ \hat{\alpha}_{21} & \hat{\alpha}_{22} & \hat{\alpha}_{23} & \hat{\alpha}_{24} & \hat{\alpha}_{25} \\ \hat{\alpha}_{31} & \hat{\alpha}_{32} & \hat{\alpha}_{33} & \hat{\alpha}_{34} & \hat{\alpha}_{35} \\ \hat{\alpha}_{41} & \hat{\alpha}_{42} & \hat{\alpha}_{43} & \hat{\alpha}_{44} & \hat{\alpha}_{45} \\ \hat{\alpha}_{51} & \hat{\alpha}_{52} & \hat{\alpha}_{53} & \hat{\alpha}_{54} & \hat{\alpha}_{55} \end{pmatrix} = \begin{pmatrix} -0.15 & -0.002 & 0.05 & -0.18 & 0.0008 \\ (0.06) & (0.001) & (0.03) & (0.007) & (0.0004) \\ -22.492 & -0.96 & 3.92 & 1.17 & 0.05 \\ (7.52) & (0.16) & (3.38) & (0.85) & (0.04) \\ 0.51 & 0.000005 & 0.08 & -0.07 & 0.0006 \\ (0.30) & (0.006) & (0.136) & (0.034) & (0.0017) \\ -1.89 & -0.05 & -5.86 & -0.59 & -0.06 \\ (7.03) & (0.15) & (3.16) & (0.8) & (0.04) \\ -0.23 & 0.007 & -0.41 & 0.0015 & -0.005 \\ (0.20) & (0.004) & (0.09) & (0.023) & (0.001) \end{pmatrix}$$

LR-test of overidentifying restrictions: $\chi^2(11) = 17.898$ [0.0840]

For a more detailed account of the various parts of this table, see footnote 12.).

analysis was undertaken on a VAR(3), (7) will imply the following conditional structural GUM representation for the nominal krone-euro exchange rate, s_t:

$$\Delta s_t = \alpha_s^* \beta' Y_{t-1} + \sum_{i=1}^{3-1} \gamma_{s,i}^* \Delta s_{t-i} + \sum_{i=0}^{3-1} \Gamma_{s,i}^* \Delta \tilde{X}_{t-i} + \Phi_s^* D_t + \tilde{u}_t \tag{8}$$

where the subscript s stands for the row pertaining to the exchange rate in (7) and $\tilde{X}$ representing the vector of all the endogenous variables in (6) that remain after having removed the real exchange rate, substituted the real interest rate differential with the nominal one and relegated lagged and contemporaneous first differences of the relative price ratio to the container of exogenous variables and deterministic terms, the D_t variable vector.[14]

Reducing the model to a parsimonious representation taking into account the possibility of a structural change in the parameters governing the dynamic responses of the variables representing the effects of investor behaviour and market dynamics, respectively, the industry-specific oil and gas equity index and the variable capturing the relative FDI movements towards the EMU and Norway, we get the following representation:

$$\begin{aligned}
\Delta s_t = & \underset{(0.005)}{0.008} + \underset{(0.1)}{0.18} \Delta s_{t-1} \underset{(0.08)}{+0.40} \Delta s_{t-2} - \underset{(0.014)}{0.095} \Delta op_t + \underset{(0.017)}{0.075} \Delta op_{t-1} \\
& - \underset{(0.008)}{0.06} \Delta(i - i^*)_t + \underset{(0.009)}{0.04} \Delta(i - i^*)_{t-1} + \underset{(0.001)}{0.0034} \Delta(I_{t-1} * SD161_t) \\
& - \underset{(0.035)}{0.09} \Delta(a_{t-1} * SD161_t) + \underset{(0.00035)}{0.0008} \Delta \mathrm{VIX}_t + \underset{(0.004)}{0.009} \Delta Seas_{t-3} \\
& - \underset{(0.036)}{0.06} ((s_{t-1} + p^*_{t-1} - p_{t-1}) + 0.023 a_{t-1} - 0.004 I_{t-1} + 0.23 v_{t-1} - 0.004 \mathrm{VIX}_{t-1}) \\
& - \underset{(0.00056)}{0.0009} ((i_{t-1} - \Delta p_{t-1}) - (i^*_{t-1} - \Delta p^*_{t-1})) \\
& + \underset{(0.014)}{0.031} ID061_t + \underset{(0.014)}{0.045} ID133_t + \epsilon^s_t
\end{aligned} \tag{9}$$

AR 1-5 test:	$F(5, 56)$	=	0.98974[0.4323]
ARCH 1-4 test:	$F(4, 68)$	=	2.1078[0.0893]
Normality test:	$\chi^2(10)$	=	3.5554[0.1690]
Heterosc. test:	$F(23, 50)$	=	0.82385[0.6876]
RESET23 test:	$F(2, 59)$	=	0.27944[0.7572]

In (9) $IDYYQ$ and $SDYYQ$ stand for, respectively, an impulse dummy that is equal to one in quarter Q of year 20YY, and a step-dummy equal to one from the Q'th quarter of

[14] In 8, α^*_s refers to a 1 x 5 parameter vector with equilibrium correction coefficients, β a $5 \times (p+q)$ matrix of cointegration parameters, while $\gamma^*_{s,i}$, $\Gamma^*_{s,i}$ and Φ^*_s stand for, respectively, a scalar, a 1×4 parameter vector and a vector containing all the parameters pertaining to the D_t variable vector. $\tilde{u}_t$ is a scalar residual.

20YY and throughout the whole sample period, YY in both cases denoting a combination of two individual numbers where the first runs from 0 to 2 while the second runs from 0 to 9. The step-dummy SD161 thus implies that we operate with a structural break in the dynamic responses to, respectively, a change in the oil specific equity price index and a change in the variable measuring the difference between foreign direct investments as a percentage of GDP in the euro area and Norway in the 1'st quarter of 2016. A one-per cent increase in the oil industry-specific equity index in this context is estimated to lead to a strengthening of the nominal krone-euro exchange rate of just short of 0.1 per cent in the quarter succeeding the change. Otherwise, we see that both the first and the second cointegrating vector in the long-run structure of Table 2 enters significantly in Equation (9), implying that a one percentage point increase in the real interest rate differential is estimated to lead to a relatively small but significant real appreciation of approximately 0.1 per cent in the long run. Compared to an estimated contemporaneous effect of about -0.25 per cent, this implies overshooting in the wake of ceteris paribus changes to the nominal interest rate.[15]

In addition to the effect that comes via the value-share of oil and gas exports in the long-term exchange rate relationship and which, if the relationship between these two quantities is based on the third cointegrating relationship in Table 2, would imply a long-term real appreciation of the krone euro exchange rate of approximately 0.23 per cent in the wake of a one percent increase in the US dollar price of oil, the oil price has according to (9) clear dynamic effects. A one percent increase in the oil price is in this context estimated to lead to an instantaneous appreciation of about 0.1 percent, and while the effect is somewhat reversed the next quarter, the effect builds up gradually to its long-run effect captured by the effect that appears via the above mentioned increase in the export value share of oil and gas.

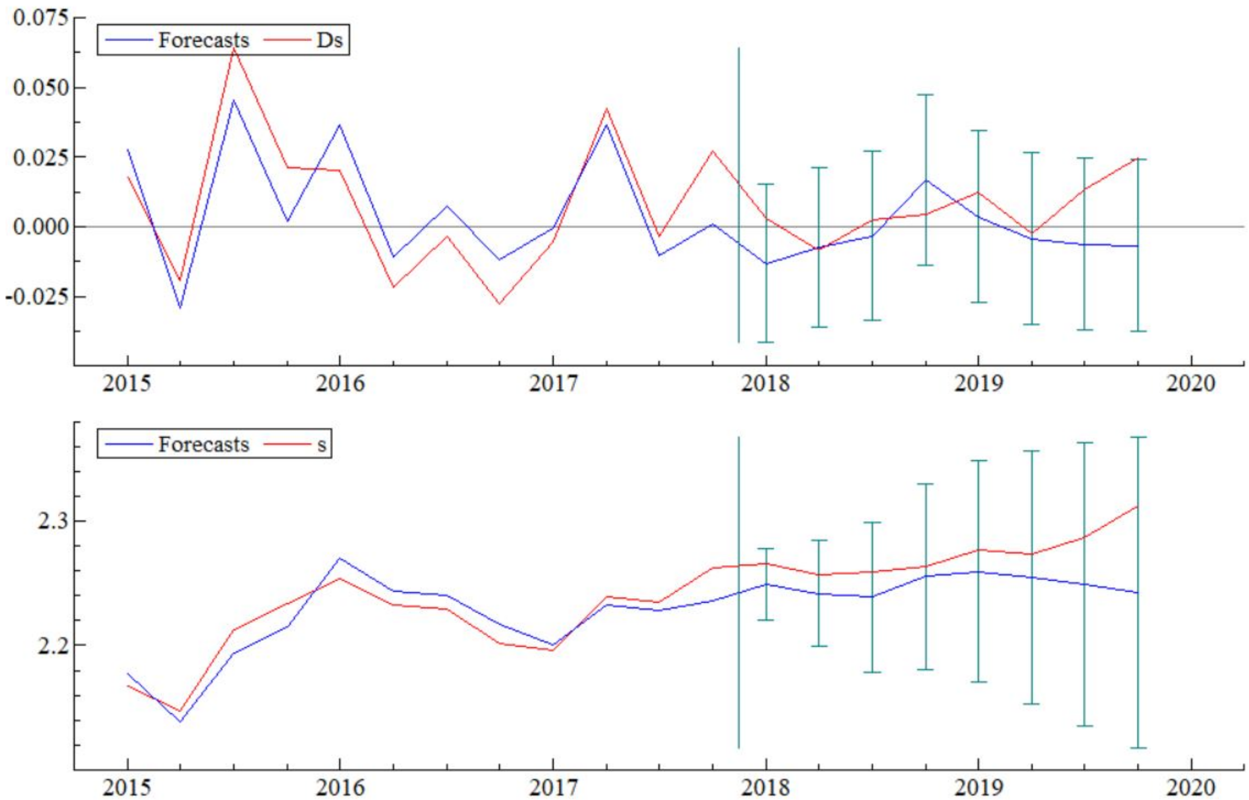
As far as the statistical properties of the contingent equation in (9) is concerned, the outcomes of the statistical tests quoted below the equation, all suggest that the model is a good candidate for the entitlement of being considered as a congruent representation of an underlying DGP. Recursive tests demonstrate, moreover, that the model and its parameters are stable.[16]

Moreover, simulating the model dynamically from 2008 onwards by linking lagged values of the endogenous variable to the previously predicted ones, indicates that the in-sample prediction properties are fairly good, in the sense that there is no tendency for the simulated values to derail (see Figure 6 in the Appendix).

[15]Note that the interest and inflation rates in (9) are measured as annualized rates in percent. When discussing the effects of a quarterly change to these variables of a one percentage point, we therefore have to multiply the coefficient by 4 or to refer to interest rate changes of a quarter of a percentage point.

[16]See Figure 4 and Figure 5 in the Appendix.

Figure 3: Dynamic Forecasts



Estimation period 2001q1 to 2017q4: 8 periods ahead dynamic forecasts

Unlike static one-step forecasts where one uses actual data for all right side variables – also the lagged values of the endogenous variable(s) – dynamic forecasts refer to forecasts made utilizing current and former forecasts of these values, including the lagged endogenous ones.

As born out by Figure 3 retaining 8 observations for the possibility of making ex ante forecasts and using the model to dynamically forecast eight periods ahead, does reveal a potential problem in the second half of 2019. However, the level forecasts are well inside the 95 percent confidence interval for the whole period.

5 Conclusion

We find empirical evidence that there is a risk premium in the process driving the krone-euro exchange rate, explaining the depreciation of the NOK exchange rate over the last four to five years.

The risk premium is captured by a number of variables: the oil price, the export value of oil and gas as a share of the total value of exports, the difference between inward foreign direct investments as a percentage of GDP in the euro area and Norway, an oil industry-specific equity index and a volatility index related to the US $S\&P$ stock market index.

These variables can be related to the behavior of investors envisaging factors such as a green shift, a weak or weakening international economic business cycle and a build-up in international and geopolitical tensions.

In the final model, the real exchange rate is estimated to weaken as oil and gas make up a smaller share of the Norwegian economy. A one per cent fall in the export share is estimated to lead to a weakening of the krone-euro exchange rate by approximately 0.23 per cent in the long run. Furthermore, a one per cent fall in the industry-specific share price index for the oil sector is also estimated to lead to a real exchange rate depreciation in the long run, though the estimated effect is rather weak.

However, combined with an outflow of capital as represented by the difference between the inward foreign direct investments as a percentage of GDP in the euro area and Norway and a rising S&P volatility index, these effects may under certain conditions contribute to a persistent negative long-term pressure on the krone-euro exchange rate.

In the short term, the krone exchange rate is to a large degree driven by changes to the US dollar oil price and interest rates, although eigen dynamics and some additional variables related to the risk premium are found to be significant as well. However, with the exception of the $S\&P$ volatility index and in contrast to what applies to the long term, the effect of these additional variables primarily appears to be valid only from 2016 onwards.

The model surpasses a panoply of tests for non-spherical noise, is stable and does seem to fulfill most requirements for being reckoned as a congruent representation of an underlying data generating process.

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6 Appendix

Figure 4: Stability Tests

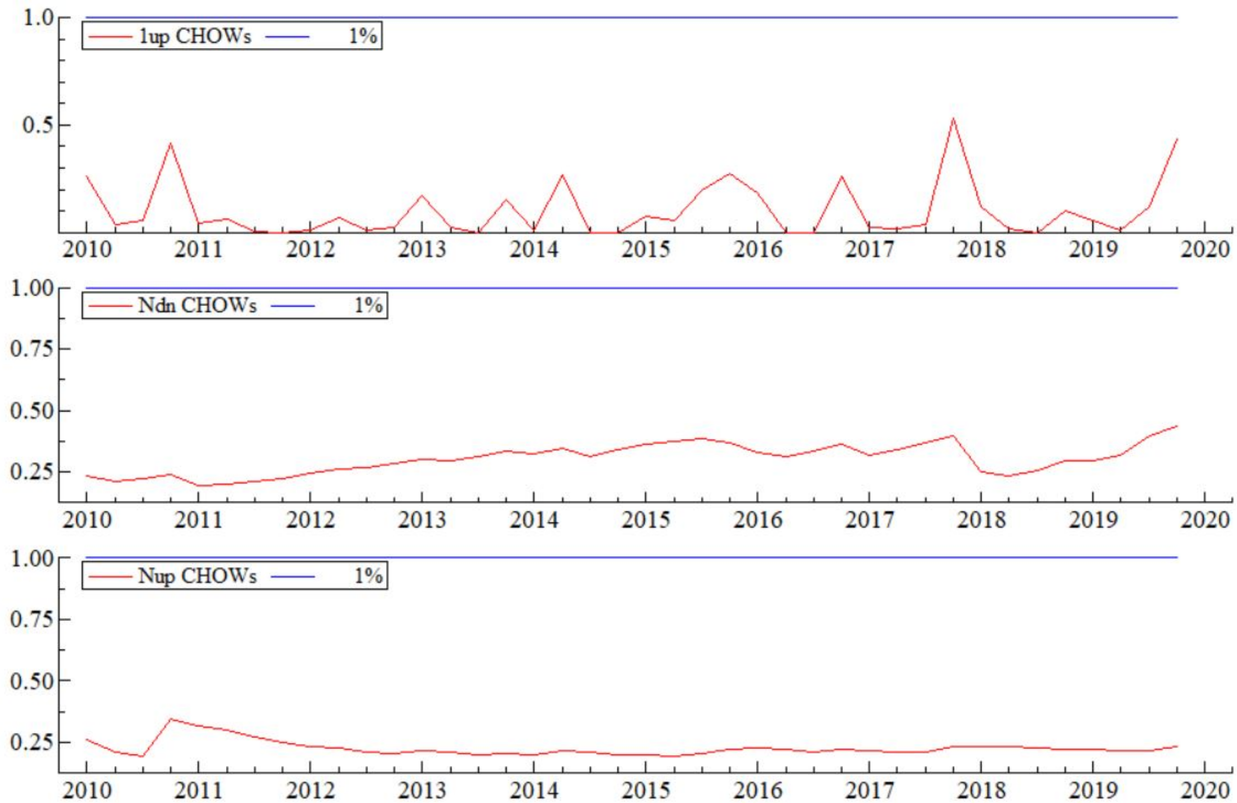


Figure 4 shows 1-step and break-point Chow tests. These are the main tests of parameter constancy and have the form:

$$(((RSS_{T+H} - RSS_T)/H)/RSS_T/T - k) \sim F(H, T - k),$$

where RSS is the residual sum of squares, k the number of right hand side variables, H the forecast horizon and T a date index. The 1-step test implies that the time horizon H is fixed at one period as the test is computed sequentially for t=T and up to t=T+H. As far as the Ndn Chow tests are concerned each point is the value of the Chow F-test for that date against the final period, here 2019Q4, scaled by its 1 percent critical values, implying that the forecast horizon N is decreasing from left to right (hence the name Ndn tests). The opposite is the case for the Nup Chow tests where each point is the value of the Chow F-test for that date against the final period in the initialization sample, here 2009Q4, implying that the forecast horizon is increasing from left to right. None of the tests shown above reject the null hypothesis of the parameters being stable over time (to a level of 1 percent) and thus corroborate the impression given by Figure 5.

Figure 5: Recursively estimated coefficients

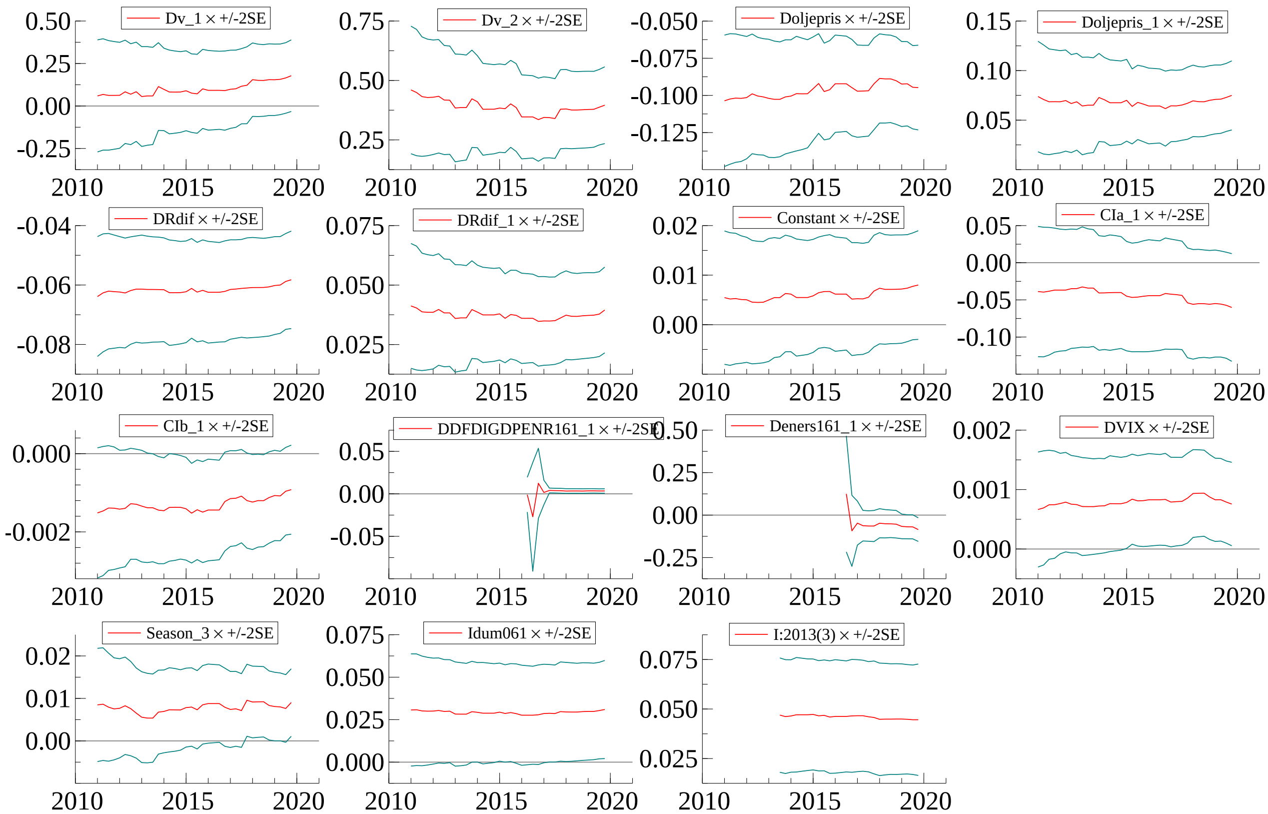
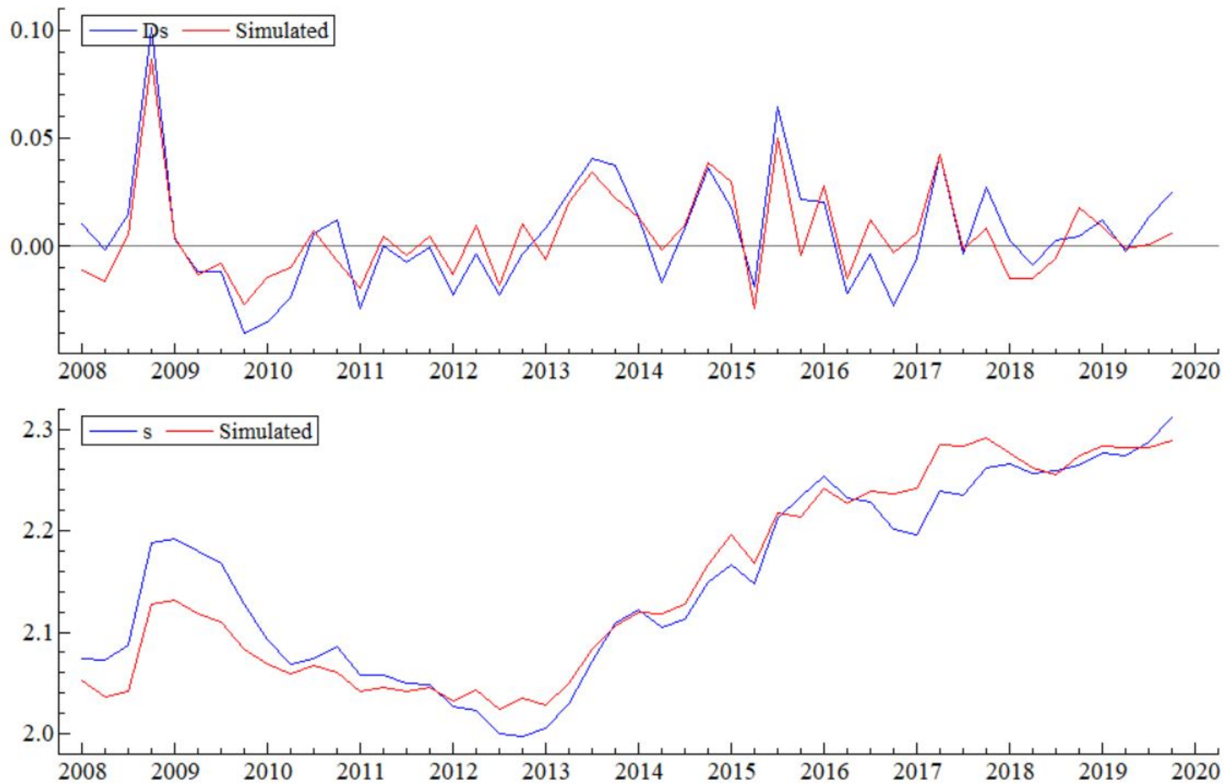


Figure 5 shows recursively estimated coefficients with the number of observations used for initialization set to 40. With the exception of the parameters pertaining to the variables that kicks in in 2016Q1, non of these coefficients lie outside the confidence interval which an investigator would have calculated as the basis for forecasting based on the first 40 observations. As far as the parameters pertaining to the two variables kicking in from 2016Q1 onwards are concerned, they both seem to stabilize fast towards their estimated values using the full sample.

Figure 6: Dynamic Simulations



Unlike static one-step forecasts where one uses actual data for all right side variables – also the lagged values of the endogenous variable(s) – dynamic forecasts, as presented in Figure 6, refer to forecasts made utilizing current and former forecasts of these values, including the lagged endogenous ones.