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Simple cross-check models for the krone exchange rate

by

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1. Introduction

In this paper we discuss simple cross-check models for the krone exchange rate. Such models may give information as to whether the exchange rate is in line with basic macroeconomic fundamentals. Norges Bank publishes forecasts for several variables, e.g. the interest rate, inflation, the output gap and the exchange rate. General equilibrium models are important tools in the forecasting process. However, as stated by Deputy Governor Jarle Bergo, *"…There is no mechanical relationship between the models the Bank uses and its forecasts…Central to this process is the use of judgement…"* (Bergo, 2006). Cross-checks are useful tools in the forecasting process as they may provide additional information not necessarily captured by the bank's macro models.

First, we look at the evolution of the real exchange rate since the beginning of the 1970s. If the real exchange rate is stationary, the future exchange rate can be predicted on the basis of deviation from Purchasing Power Parity (PPP). Second, we discuss some simple econometric models where the exchange rate is determined by variables like the price and interest rate differential relative to Norway's trading partners and the oil price.

2. The real exchange rate in Norway

We define the real exchange rate as

$$(1) \quad Q = \frac{EP*}{P}$$

where E is the nominal exchange rate (an increase indicates a depreciation of the krone), P is the price level in Norway and P* is the price level of the trading partners. Chart 1 shows the

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nominal trade weighted exchange rate (TWI)[2], the relative price level between Norway and its trading partners (consumer prices) and the corresponding real exchange rate, all series indexed from 1971 (for all series an increase indicates a real depreciation). The real exchange rate has been fairly stable over time, but in recent years somewhat stronger than the historical average.

Since the beginning of the 1970s Norway has experienced different monetary policy regimes. As shown in chart 2, up to the beginning of the 1990s inflation was high and volatile, and in periods higher than inflation abroad. Moreover, up to the mid-1980s the Norwegian economy was characterised by capital and credit market regulations and notwithstanding a "fixed" exchange rate regime, the nominal exchange rate was frequently devalued. In the second part of the 1980s, in parallel with falling inflation, capital and credit markets were deregulated. In the 1990s monetary policy continued to be oriented towards stabilising the exchange rate, while since around the change of the millennium, focus has been on stabilising inflation. Despite different monetary policy regimes, the real exchange rate seems to have been mean reverting over time.

If the real exchange rate displays mean reversion, deviation from the mean may indicate the future direction of the real exchange rate or - for a given path of the price differential – the nominal exchange rate. Whether the real exchange rate has been mean reverting – or in econometric terms stationary - can be tested empirically. Let, in accordance with equation (1)

(2) $q = e + p* - p$

where q is the log of the real exchange rate, e is the log of the nominal exchange rate, p is the log of the Norwegian price level and p* is the log of the foreign price level. The Augmented Dickey-Fuller test (ADF) runs the regression

(3) $\Delta q_t = \alpha + \rho q_{t-1} + \sum \beta_i \Delta q_{t-i} + u_t$

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[2] In Norwegian, "konkurransekursindeksen".

Under the null hypothesis of non-stationarity is $\rho=0$, while $\rho<0$ under the alternative hypothesis of stationarity.[3] Given that the real exchange rate is stationary the half-life can be calculated as $\ln(\frac{1}{2})/\ln(1-\rho)$ and provide a forecast for the real exchange rate.[4]

The degree of mean reversion of the real exchange rate is related to the Purchasing Power Parity (PPP)-hypothesis. Earlier tests of PPP were frequently undertaken by running the regression $e_t=\alpha+\beta(p-p^*)_t+u_t$, where u is an error term. Absolute PPP (equal price levels) implies that $\alpha=0$ and $\beta=1$ and it would hold continuously if u_t is zero for all t. Relative PPP implies that changes in the exchange rate are equal to changes in the price level differential, that is, $\alpha\neq0$ and $\beta=1$.[5] The stationarity test above (equation 3) is a dynamic test of relative PPP, dynamic in the sense that the real exchange rate may deviate from the mean at a certain point in time, but – if stationary – will revert to it over time. It is a test of relative PPP in the sense that the mean may not necessarily imply equal price levels in the two countries.[6]

Based on the data displayed in chart 1, the real exchange rate has been stationary (the ADF p-value is equal to 0.02).[7] However, different studies report different results regarding the time series properties of the real exchange rate in Norway, probably reflecting different time periods examined and different measures of the real exchange rate used. While Akram (2006) finds that the trade weighted real exchange rate is stationary in the period 1972Q2-2003Q4, Hungnes and Bjørnland (2002) and Hungnes and Bjørnland (2006) report a non-stationary trade weighted real exchange rate for respectively 1983M1-1999M12 and 1983Q1-2002Q2. Furthermore, Bjørnstad and Jansen (2007) find that the NOKEURO real exchange rate is non-stationary for the period 1983Q1-2006Q3.

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[3] For more details and examples of the test used on real exchange rates, see Akram (2006).

[4] The half-life is the average time it takes for a deviation from the mean to half. For example, if the half-life is 12 months and the real exchange rate is 4 per cent stronger than the mean, the real exchange rate is expected to weaken and be only 2 per cent stronger than the mean in 12 months, 1 per cent stronger than the mean in 24 months and so on.

[5] It is far beyond the scope of this paper to discuss and review the international PPP-literature. To some extent evidence seems to support relative PPP in the long run, though the speed of convergence is uncertain. The reference list discussing PPP is unlimited, but Sarno and Taylor (2002) and Taylor and Taylor (2004) provide a review of the literature with detailed references.

[6] Patterson (2000) refers to this test as the "very weak form PPP-test"

[7] The p-value indicates the probability that the null hypothesis of non-stationarity is true. Hence a low p-value rejects the null and suggests stationarity.

Table 1 reports the probability value of the ADF null hypothesis of non-stationarity for different time periods, different measures of the real exchange rate (trade weighted and nokeuro) and different frequency of the data (quarterly, monthly). In the upper panel the time period, the measure of the real exchange rate and the frequency chosen correspond to the ones used in the papers mentioned above. Note that these probability values are not taken directly from their papers, but are <u>my own calculations</u> based on the same time period, the same measure of the real exchange rate and the same data frequency used in their papers. All the probability values are consistent with the time series properties of the real exchange rate reported in their respective papers. The lower panel shows the probability values for different time periods based on the real exchange rate in chart 1. For some periods the null is rejected, while for others it is not.

As mentioned above, based on the whole sample from 1971M3 to 2008M2, and in line with Akram (2006), the real exchange rate has been stationary. Overall, however, the results regarding the time series properties of the real exchange rate in Norway are mixed. For the purpose of a cross-check, we assume that that deviation from PPP – the real exchange rate's deviation from the mean - may provide information of future exchange rate developments. However, as follows from the discussion above, predictions based on PPP must be interpreted with care.

3. Simple cross-check models for the nominal exchange rate

In this section we discuss models where the exchange rate is determined by a small set of macroeconomic variables. First, we look at some key macroeconomic variables which may determine the krone. Second, we discuss the background for and some problems with using our simple models. Third, we discuss the estimation results.

3.1 Which variables can explain the krone exchange rate?

As follows from the discussion above, the price differential is one candidate to explain the nominal exchange rate, in particular in periods where inflation in Norway has differed from inflation abroad. Moreover, market participants frequently report that they consider the interest rate differential and the oil price as key drivers for the exchange rate.

Chart 3 and 4 show the trade weighted nominal exchange rate (TWI) and the three-month interest rate differential relative to the trading partners, from 1986 and 1999 respectively. In some periods higher interest rate differential seems to go hand in hand with weaker krone, in other periods with stronger krone and in some periods there seems to be no correlation. Chart 5 shows the twelve-month moving correlation coefficient between the change of the exchange rate and the change of the interest rate differential.[8] The relationship has changed over time. In the 1980s and the 90s the interest rate was largely used to stabilise the exchange rate: A tendency for the krone to depreciate was met by higher interest rate. Hence higher interest rate differential was associated with weaker krone (positive correlation in chart 5). In a regime with inflation targeting higher inflationary pressure and higher capacity utilisation are typically met by higher interest rate and an appreciation of the krone. Hence higher interest rate differential is largely associated with stronger krone (negative correlation in chart 5). This changed pattern may have implications for how the relationship between the exchange rate and the interest rate differential should be modelled.

Chart 6 shows the trade weighted exchange rate and the oil price (in USD) from the end of the 1980s. Up to around 2002 the oil price varied roughly between 10 and 30 USD. As from 2003, however, the oil price has increased substantially. According to economic theory, higher oil price may imply more production of non-tradable goods relative to tradable ones, a change which may require an appreciation of the real exchange rate.[9] Furthermore, higher oil price may increase oil-related investments and demand for oil-related stocks and hence result in a stronger krone. In addition, one cannot exclude the possibility that pure psychological factors among market participants lead to higher krone demand when the oil price rises.

It follows that the price differential, the interest rate differential and the oil price are candidates to explain the krone exchange rate. In this paper we estimate single-equation equilibrium correction models like

$$(4) \quad \Delta e_t = \alpha + \beta_1 \Delta e_{t-1} + \beta_2 \Delta(i - i^*)_t + \beta_3 \Delta oilp_t + \lambda[e_{t-1} - (i - i^*)_{t-1} - oilp_{t-1} - (p - p^*)_{t-1}]$$

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[8] Each observation in the chart shows the correlation coefficient between the last twelve changes in the interest rate differential and the changes in the exchange rate, $corr[\Delta(i\text{-}i^*), \Delta e]$.

[9] See Torvik (2003) for a more elaborate discussion.

where *e* is the log of the nominal exchange rate (an increase indicates a depreciation), *p* is the log of the Norwegian price level, *p** is the log of the foreign price level, *i* is the Norwegian interest rate, *i** is the foreign interest rate and *oilp* is the USD oil price. Δ denotes the one period change in the variables. By estimating the equation and setting all short-term dynamics equal to zero (Δ=0) a long-term relation between the exchange rate and the macroeconomic variables results. The long-term relation is given by

$$(5) \quad e = c_o + c_1(p - p^*) + c_2(i - i^*) + c_3 oilp$$

where the coefficients c_0, c_1, c_2 and c_3 are functions of the coefficients in equation (4). The long-term relation is taken to be the "model-predicted exchange rate" – *the cross-check.*

3.2 Background for and some basic problems with the models

In this section we discuss the background for and some problems with the use of our simple cross-check models. Purchasing power parity (PPP) and uncovered interest rate parity (UIP) provide a theoretical background. In accordance with equation (1) we define the real exchange rate as

$$(6) \quad q = e + p^* - p$$

where q is the log of real exchange rate. Let

$$(7) \quad \text{PPP}: \quad e^{eq} = p - p^* \quad \text{and}$$

$$(8) \quad \text{UIP}: \quad \Delta e^e = (i - i^*)$$

where e^{eq} is the (PPP-implied) equilibrium nominal exchange rate and Δe^e is the expected change of the exchange rate. Assume that the expected change of the exchange rate depends on the exchange rate's deviation from the equilibrium rate, that is

$$(9) \quad \Delta e^e = \sigma(e - e^{eq}) \qquad \sigma < 0$$

Combining (7), (8) and (9) gives

(10) $(i - i^*) = \sigma[(e - (p - p^*)]$ or with $w = 1/\sigma < 0$

(11) $e = (p - p^*) + w(i - i^*)$

Hence given PPP, UIP and expectations formed as in equation (9), the exchange rate is determined by the interest rate differential and the price level differential.

Any meaningful relation between economic variables must balance, that is, the equation must be stationary. Stationarity requires that all non-stationary variables cointegrate. Assume that e and (p-p*) cointegrate, in which case PPP constitutes an equilibrium condition between the exchange rate and the price differential. Then PPP alone would be sufficient to predict the future exchange (depending on the validity on conditioning exchange rate predictions on the price level). However, if PPP does not hold, more explanatory variables are needed to produce a stationary equation. Johansen and Juselius (1992) find that the price differential alone is not sufficient to obtain a stationary equation and include the interest rate differential to achieve stationarity.[10] Moreover, Bjørnland and Hungnes (2006) find that PPP does not hold on Norwegian data, but by including the interest rate differential they obtain a stationary equation.[11]

However, there is no reason to believe that the exchange rate, the interest rate differential and the price differential will always and by nature cointegrate. In general, more variables may be needed to obtain a stationary equation, like

(12) $e = (p - p^*) + w(i - i^*) + \beta x$

where x could be any vector of macroeconomic variables explaining the exchange rate. This approach is taken by Bjørnstad and Jansen (2007) who, by updating the paper by Bjørnland and Hungnes (2006), argue that including the oil price is necessary to obtain a stationary equation.[12] The need to include the oil price to achieve a stationary equation reflects the importance of the oil price as determinant of the krone exchange rate in recent years. As

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[10] Johansen and Juselius (2002) estimate on data for UK (effective exchange rate, 1972Q1-1987Q2).
[11] Bjørnland and Hungnes (2006) estimate on data for Norway (trade weighted exchange rate, 1983Q1-2002Q2)
[12] Bjørnstad and Jansen (2007) estimate on data for Norway, (NOKEURO, 1983Q1-2006Q3).

shown in chart 6 in the text, the krone has appreciated considerably since the beginning of 2004, while at the same time the oil price has more or less trebled.

Some problems exist regarding the economic interpretation of the long-term relation. First, it is not clear how the interest rate differential in the long-term relation should be interpreted. One could argue that in the long run the exchange rate equals its equilibrium value and hence the expected change is equal to zero. Then, according to UIP the interest rate differential is zero and should be left out of the long-term relation in the first place.[13] However, in this paper we take a pragmatic view, follow the literature and include the nominal interest rate differential in the long-term relation of the model, not least because empirically the models fit the data better with the interest rate differential included in the long-term relation.[14] In most of the models, however, the price differential is excluded as the models are estimated over periods with low and stable inflation both in Norway and abroad.

Second, the long-term relation does not necessarily (and will most probably not) reflect the "equilibrium exchange rate", normally defined as the exchange rate consistent with internal and external balance. To avoid any confusion with equilibrium exchange rates in a broader sense, the term "model predicted exchange rate" is used when referring to the long-term relation of the models. More troublesome, it is not clear which are the economic forces driving the exchange rate back to the value following from the long-term relation. It seems fair enough to assume that an unexpected rise in the interest rate differential and the oil price will result in a stronger Krone, but it is not clear by how much. The estimated long-term relation merely reflects statistical relationships between the exchange rate and other variables like the interest rate differential and the oil price in the past. It is not clear that these statistical relationships constitute a stable long-run relation.[15]

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[13] With a zero interest rate differential in the long-term relation, the nominal exchange rate would be driven by the price differential and the oil price. This means that the real exchange rate – deviations from PPP – would be determined by the oil price. According to economic theory, this makes sense as higher oil price may imply more production of non-tradable goods relative to tradable ones, a change which may require an appreciation of the real exchange rate. See Torvik (2003) for a more elaborate discussion.

[14] One could perhaps argue (admittedly somewhat ad hoc) that UIP applies for a horizon longer than the one needed for the long-term relation of the model to settle. While estimates of λ in equation (4) indicate a relatively fast reversion to the long-term relation, Chinn and Meredith (2005) find that UIP seems to hold better for longer horizons. Furthermore, one might argue – again somewhat ad hoc admittedly – that a non-zero interest rate differential could reflect a non-zero risk premium (see discussion of the risk premium below). However, it is not clear what value the risk premium should take in long-run equilibrium, the best guess perhaps being zero.

[15] I would like to thank Geir Alstad for valuable discussion and comments on this point.

Moreover, the cross-check models are not necessarily suitable for predicting the future exchange rate. First, in contrast to general equilibrium models, like the macro models of the Bank[16], they do not take the endogenous interaction between the different variables into account. Hence predictions are not necessarily consistent with the economy moving towards equilibrium like achieving the inflation target. To illustrate, normally, in a general equilibrium model an appreciation pressure will lead to lower interest rate, which will feed back on the currency and reduce the original appreciation pressure. One advantage of an equilibrium model is that the interest rate can be set under the consideration of interaction between all the variables so that the economy moves towards equilibrium over time (inflation on target, production equal to potential and the real interest rate equal to the neutral level).

Second, simple cross-check models do not necessarily "understand" that expected changes in the interest rate differential may be reflected in today's exchange rate. Before discussing this, it is useful to have a closer look at UIP, in particular what UIP implies and what it does not imply. Starting with equation (8) UIP can be written as

(13) $e_t = E_t e_{t+1} - (i - i^*)_t$

By leading equation (13) one period we obtain

(14) $e_{t+1} = E_{t+1} e_{t+2} - (i - i^*)_{t+1}$

Substituting (14) into (13) and using the law of iterated expectation gives

(15) $e_t = E_t e_{t+2} - E_t (i - i^*)_{t+1} - (i - i^*)_t$

Continuing this iteration process indefinitely we achieve

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[16] The general equilibrium modell NEMO (Norwegian Economy MOdel) is discussed in a box in Monetary Policy Report 2007/3 and in Brubakk et. al. (2006). The model "1a" is discussed in Husebø et. al. (2004).

$$(16) \ e_t = E_t e_{t+\infty} - E_t \sum_{k=0}^{\infty} (i - i^*)_{t+k}$$

- UIP implies that today's exchange rate is determined by the expected long-term exchange rate ("$E_t e_{t+\infty}$"), today's interest rate differential and all future expected interest rate differentials.[17] A fall in $E_t e_{t+\infty}$ (a stronger expected long-term exchange rate), an increase in today's interest rate differential and an increase in expected future interest rate differentials will appreciate the exchange rate today. The higher is the increase in the expected interest rate differentials and the longer the differentials are expected to persist, the stronger is the effect on today's exchange rate.

- UIP implies that expected changes in the interest rate differentials are reflected in today's exchange rate.[18] Put differently, the exchange rate will not react to *expected* changes in the interest rate differential.

- UIP implies that the exchange rate will react to *unexpected* – surprising - changes in the interest rate differential. Shocks to the economy (news) may pull the exchange rate away from what was expected. That the exchange rate develops differently from expectations does not imply that UIP does not hold, nor does it imply that not all available information was reflected in the exchange rate. Hence correlation between the exchange rate and the interest rate differential may be consistent with UIP, as – in a credible inflation targeting regime - an unexpected rise (fall) in the interest rate differential will cause an appreciation (a depreciation). Whether UIP holds or not depends on whether the expected change in the exchange rate is equal to the interest rate differential thereafter (that is, after the immediate effect has taken place).[19]

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[17] Note that for k=0 the first element of the sum is today's interest rate differential, $(i-i^*)_t$

[18] A positive interest rate differential implies that the currency with the higher interest rate is expected to depreciate over time. For example, if the twelve-month interest rate differential is two percentage points, UIP implies that the krone is expected to depreciate by 2 per cent over the next year.

[19] It follows that UIP is consistent with money market rates reacting to central bank decisions if the decisions are surprising the market. Assume that the market is uncertain as to the size of an interest rate increase, with 50 percent weight attached to respectively 25 and 50 basis points. Then, the expected interest rate increase would be 37.5 basis points, the effect on today's exchange rate depending on how long the interest rate differential would be expected to last (see equation 16). When the interest rate change materialises the exchange rate will react immediately after the announcement of the decision, completely in line with UIP: A 50-points rise would

Frequently UIP is adjusted by a risk premium, that is

(17) $e_t = E_t e_{t+1} - (i - i^*)_t + rp_t$

A non-zero risk premium implies that expected return of investing in domestic currency is different from expected return of investing in foreign currency. This may be consistent with equilibrium in capital markets, meaning that investors emphasise other factors in addition to expected return. An increase in the risk premium means that investors find kroner more risky and hence they want to reduce the amount of kroner investments in their portfolios. This leads to either a weaker Krone ($\Delta e = \Delta rp > 0$), higher domestic interest rate ($\Delta i = \Delta rp$) or a combination. Note that even if UIP does not hold, expected interest rate differentials may still to some extent be reflected in today's exchange rate. However, depending on the sign and the size of the risk premium the exchange rate will differ from the UIP-implied.

As noted above, the cross-check models do not necessarily "understand" that expected changes in the interest rate differential may be reflected in today's exchange rate. This may have serious problems when the models are used to predict the future exchange rate because the models threat all changes in the interest rate differential as if they were unexpected. Assume that the short-term interest rate differential is expected to increase and *assume* that the expected increases are reflected in today's exchange rate. At the moment when the expected increases in the interest rate differential materialise the model predicted exchange rate will appreciate despite the fact (here assumption) that the interest rate changes were priced into the exchange rate in the first place. This means that the prediction will exaggerate the degree of appreciation: The model predicted exchange rate path will imply a stronger exchange rate than what is expected to come about.

This failure is typical for econometric models like our cross-checks, which are based on pure statistical correlations between variables in the past. To fully overcome the problem, a forward looking model is needed, where expectations are modelled in line with how market participants value financial variables: They look into the future and value what they see into

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constitute a surprise upwards relative to the expectations and hence an appreciation, while a 25-points rise would constitute a surprise on the downside, leading to a depreciation.

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today's price! To some extent one can overcome the problem by using longer-term interest rate differentials as explanatory variable for the exchange rate. Hence in this paper interest rates at twelve-month maturity are used. However, using longer-term interest rate differentials as explanatory variables cannot fully compensate for the failure of appropriately capturing market's expectations and the extent to which expected interest rate changes are reflected in today's exchange rate. Moreover, the problem of not capturing market's expectations is first and foremost a problem when using the models to predict future exchange rates over longer horizons. The models may properly explain the exchange rate in the past and provide some ideas of the direction of the exchange rate in the nearest future.

Another issue that arises is the linearity – the simplicity – of the models. Nobody really believes that exchange rate models are stable and will hold over any future. The break-down of such models is actually inherent in all models that explain the exchange rate: To the extent that the models are successful and used for trading, arbitrage will be done and the model no longer valid. Hence it seems to be the rule that simple models for the exchange rate "break down" and must be re-estimated. This means that the models are better suited to explain the exchange rate in the past than predicting it in the future. Earlier studies at Norges Bank point to non-linear effects of the oil price (Akram, 2004). Furthermore, around 2000-2001 non-linear combinations of high interest rate differential, declining global stock markets and low global exchange rate volatility were seen as driving forces for the Krone exchange rate (Naug, 2003). However, in the last years - from around the beginning of 2002 – simple linear relationships between the exchange rate, the interest rate differential and the oil price seem to exist. Even though these models may break down in the future, they may be useful today.

3.3 Estimation results

In this paper the preferred model – estimated on *monthly* data from the beginning of 2002 – implies a long-term relation as

$$(18) \quad e = 4.9 - 2.5\,(i_{12} - i_{12}^{*}) - 0.06\,\text{oilp}$$

where e is the log of the trade weighted exchange rate (TWI) and where the twelve-month interest rate differential has been used to capture future short-term expectations. The price differential has been excluded as inflation and inflation expectations have been low both in

Norway and abroad over the estimation period. The model focuses on the two factors emphasised by the market, the interest rate differential and the oil price.[20] Estimation details of this and other models discussed below are shown in table 2.

Chart 7 shows the exchange rate and the predicted exchange rate based on model (18).[21] As discussed above the model predicted exchange rate cannot be interpreted as "the equilibrium exchange rate", the level of the exchange rate consistent with both internal and external balance. It merely reflects statistical relations between the exchange rate, the interest rate differential and the oil price in the past. However, to the extent that such a relationship exists, deviations from the model predicted exchange rate may be interpreted as temporary - driven by other factors than the interest rate differential and the oil price (different kind of "themes" in the market). Hence the exchange rate's deviation from the model predicted exchange rate may provide some information about possible exchange rate developments in the very nearest future.

Estimated on *weekly* data, the long-term relation is given by

$$(19) \quad e = 5.2 - 2.6\,(i_{12} - i_{12}^{*}) - 0.04\,\text{oilp}$$

Chart 8 shows the exchange rate and the model predicted exchange rate. The picture is similar to the one based on weekly data. Both may be useful depending on the question at hand.

The simple model fits the data better from the beginning of 2002. Prior to that, non-linear effects as those suggested by Naug (2003) seem to be necessary to improve the fit. Chart 9 shows the exchange rate and the predicted exchange rate based on model (18), estimated on

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[20] To interpret the coefficients in equation (18), note that the exchange rate and the oil price are in logs and that an interest rate differential of one percentage point (hundred basis points) is denoted as "0.01" in the data. Also note that if the level of a variable increases by one per cent, the log of the variable increases roughly by 0.01. This implies that if the interest rate differential increases by one percentage point, the log of the exchange rate declines by 2.5 x 0.01 = 0.025, that is, the exchange rate declines (appreciates) by 2.5 per cent. Furthermore, if the oil price increases by 1 per cent, the log of the exchange rate declines by 0.06 x 0.01 = 0.0006. Correspondingly, a ten per cent increase in the oil price leads to a decline in the log of the exchange rate equal to 0.006, that is, the exchange crate appreciates by 0.6 per cent. In fact, in most of the models discussed below, the estimation results indicate that a ten per cent increase in the oil price leads to roughly an appreciation of ½ per cent.

[21] This is the chart referred to as "chart 7" in the box "cross-checks for the krone exchange rate" in Monetary policy report 1/08 (the axes are reverted in the *Report*).

monthly data from the beginning of 1999. In 1999-2001 the deviations between the exchange rate and the model predicted exchange rate are substantial, indicating that the model has little explanatory power in this period. One could perhaps argue that it took some time for the inflation targeting regime to settle. Hence it would take some time before we would see a stable relationship between the exchange rate and the macroeconomic variables. Furthermore, we could include non-linear effects to achieve a better fit in the period 1999-2001, but it would not help us much when it comes to how we use the model today.

As discussed above, the models are better suited to explain the past than predict the future. As the charts above reveal, the krone has largely appreciated since the trough in the beginning of 2004. Since then, and in particular from the beginning of 2007, the krone has strengthened. Model (18) can be used to decompose the causes of the appreciation. Chart 10 shows total appreciation of the exchange rate (black), the model predicted appreciation (red) and the share of the model predicted appreciation caused by respectively the oil price (green) and the interest rate differential (blue). According to this model, the oil price has been a stronger force than the interest rate differential, in particular since 2004. But also from the beginning of 2007 the oil price has been slightly more important as determinant of the exchange rate.

Interestingly, the analysis of what has driven the krone in recent years does not hinge on the simple model (18). More advanced studies, like Bjørnstad and Jansen (2007), give broadly the same result. Bjørnstad and Jansen (2007) estimate a model for the NOKEURO exchange rate on quarterly data from first quarter 1983 to third quarter 2006. Their long-term relation is roughly equal to[22]

$$(20) \quad e = c_o + (p - p^*) - 2.0\,(i_3 - i_3^*) - 0.06\,\text{oilp}$$

As Bjørnstad and Jansen (2007) cover a period with high and volatile inflation both abroad and in Norway, the price differential needs to be included in the model. For the same reason, they specify a model with the real interest rate differential in the long-term relation. However,

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[22] The authors have explained that their interest rates are three-month *non-annualised* rates. To annualise their rates (to make the results comparable with mine) the coefficient of the interest rate differential in the long term relation must (roughly) be divided by four (as annualised three-month interest rates are roughly four times as large as non-annualised three-month rates). Doing this their coefficient is around minus two, somewhat lower than (in absolute value), but not very different from mine. Also their coefficient of the oil price is roughly equal to the coefficients in my models.

in recent years – say from the mid 1990s - inflation expectations have been low and stable both in Norway and abroad (see chart 2 above). It seems reasonable to believe that in recent years the price differential has been less important than the interest rate differential and the oil price for exchange rate developments.[23] For the same reason, changes in the real interest rate differential have been dominated by changes in the nominal one. Accepting this – that is, by disregarding the price differential and by interpreting the real interest rate differential as the nominal one - the coefficients reported by Bjørnstad and Jansen (2007) are roughly in line with mine, though with a somewhat smaller effect of the interest rate differential. For comparison, chart 11 shows the same decomposition as in chart 10, but calculated on the basis of equation (20), roughly equal to the long-term relation in Bjørnstad and Jansen (2007). Also according to their model the oil price seems to have been an important driver of the krone exchange rate (NOKEURO) in recent years. This should not come as a surprise as Bjørnstad and Jansen (2007) themselves emphasise the need of including the oil price in the model to obtain a stationary equation (see footnote 23).

Model (18) and (19) above are estimated on the trade weighted exchange rate (TWI). Estimating on NOKEURO gives the long-term relation

$$(21) \quad e = 2.3 - 2.1(i_{12} - i_{12}^*) - 0.08 \, \text{oilp} + 0.24 \, \text{usdeuro}$$

where the (log of the) USDEURO has been included in the long-term relation (an increase indicates a depreciation of USD relative to EURO). Chart 12 shows the exchange rate and the model predicted exchange rate.

Furthermore, the models may be extended in the past. By including the price differential and estimating from 1988, the long-term relation is given by

$$(22) \quad e = 3.9 - 0.9(i_{12} - i_{12}^*) - 0.09 \, \text{oilp} + 0.7 \, \text{p} - 0.6 \, \text{p}*$$

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[23] In fact, Bjørnstad and Jansen (2007) states that "…The reduced difference in inflation between Norway and the eurozone can hardly explain that the krone appreciated towards euro after 2004q1 …A possible driving force for this appreciation may however be… [that] …the oil price was more than doubled in the period…" (page 8).

The exchange rate and the model predicted exchange rate are shown in chart 13. The model predicted exchange rate is somewhat "choppy", probably caused by the price differential. Excluding the price differential yields the long-term relation

(23) $e = 4.8 - 0.7(i_{12} - i_{12}^*) - 0.05\,\text{oilp}$

As shown in chart 14, the model predicted exchange rate then becomes less "choppy". However, the model predicted exchange rate in chart 13 and 14 are quite similar, suggesting that the price differential has not been the most important driver of the exchange rate from the beginning of the 1990s (in line with the fact that inflation has been low and stable both in Norway and abroad in the period). The models estimated on data from 1988 are just meant to illustrate "what would happen" if the models were extended in the past. No dummy variables are included in the models. In most other studies estimating exchange rate equations over a period covering different monetary policy regimes dummies are (legitimately) included in the model, as in Bjørnland and Hungnes (2002), Bjørnland and Hungnes (2006) and Bjørnstad and Jansen (2007).

Overall, the preferred model is the one estimated on data from 2002 (model 18). The exchange rate's deviation from the model predicted exchange rate may be interpreted as temporary - driven by other factors than the interest rate differential and the oil price – and may provide some information about exchange rate developments in the nearest future. As such they may give valuable information as simple cross-checks in the forecasting process at the bank. However, as discussed above, care should be taken when the models are used to predict the exchange rate.

4. Conclusion

- Data suggest that the relative price differential, the relative interest rate differential and the oil price are important determinants of the krone exchange rate. This view is supported not only by this study. Other studies, like Akram (2004, 2006), Hungnes and Bjørnland (2002), Hungnes and Bjørnland (2006), Bjørnstad and Jansen (2007) and Naug (2003) also confirm that these variables are key drivers of the krone exchange rate. Moreover, in periods with low and stable inflation both in Norway and abroad, the relative price differential seems to be less important as determinant of the krone.

- The relative importance of the price differential, the interest rate differential and the oil price as drivers of the krone exchange rate may vary over time. In some periods the interest rate differential seems to be more important, in other periods the oil price is more dominant. And of course, in periods with high and volatile inflation the relative price differential has been essential. Moreover, in some periods non-linear effects seem to be important (Akram, 2004 and Naug, 2003). As from the beginning of 2002 linear models seem to have been able to describe the exchange rate fairly well.

- The models in this paper are first and foremost used as "cross-checks" for the exchange rate and may provide some information as to whether the exchange rate is in line with basic fundamentals, given how these fundamentals have been statistically varying with the exchange rate in the past. Care should be taken when interpreting the models:
  - The model predicted exchange rate cannot be taken to be the equilibrium exchange rate in a broader sense
  - The models are just simple single-equation models and not well designed for policy analysis. To analyse effects of policy, a *structural* equilibrium model is needed, where the interest rate can be set under the consideration of interaction between all the variables so that the economy moves towards equilibrium over time (inflation on target, production equal to potential and the real interest rate equal to the neutral level).
  - The models do not necessarily understand that expected changes in the interest rate differential may be reflected in today's exchange rate. This may

17

exaggerate the model predicted appreciation if the interest rate differential is expected to increases in the future.

o Despite these shortcomings, the models are useful, not least to explain what has determined the krone exchange rate in the past. Combined with the proper use of a structural equilibrium model they may help improving the krone exchange rate analysis.

Table 1. Probabiliy values for the null-hypothesis of non-stationarity of the real exchange rate. (ADF-tests)

	Sample	Real exchange rate based on trade weighted (TWI)	Real exchange rate based on NOKEURO
Bjørnland/Hungnes (02	83m1-99m12	0.4	
Bjørnland/Hungnes (06)	83q1-02q2	0.4	
Bjørnstad/Jansen (07)	83q1-06q3		0.13
Akram (2006)	72q1-03q4	0.02	
Real exchange rate, chart 1	71m03-08m02	0.02	
Real exchange rate, chart 1	81m06-08m02	0.07	
Real exchange rate, chart 1	86m01-08m02	0.10	
Real exchange rate, chart 1	99m01-08m02	0.28	
Real exchange rate, chart 1	01m03-08m02	0.07	

Table 2 Estimation results

	Model 18 Dep. var= TWI			Model 19 Dep. var= TWI				Model 21 Dep. var= nokeur	
con	1.43 (3.41)		con	0.26 (3.19)			con	0.85 (4.2)	
Δkki_{-1}	0.19 (1.72)		Δkki_{-1}	0.28 (5.83)			$\Delta nokeur_{-1}$	0.25 (2.34)	
$\Delta olje$	-0.05 (-3.10)		$\Delta olje$	-0.03 (-3.77)			$\Delta olje$	-0.001 (-2.87)	
$\Delta(i-i^*)$	-3.12 (-3.05)		$\Delta(i-i^*)$	-2.90 (-6.11)			$\Delta(i-i^*)$	-2.30 (-2.18)	
kki_{-1}	-0.29 (-3.46)		kki_{-1}	-0.05 (-3.24)			$\Delta usdeur$	0.08 (1.35)	
$(i-i^*)_{-1}$	-0.75 (-2.99)		$(i-i^*)_{-1}$	-0.13 (-2.64)			$nokeur_{-1}$	-0.37 (-4.32)	
$olje_{-1}$	-0.02 (-2.19)		$olje_{-1}$	-0.002 (-1.73)			$(i-i^*)_{-1}$	-0.79 (-2.91)	
R^2	0.44		R^2	0.27			$olje_{-1}$	-0.03 (-2.77)	
s	0.012		S	0.006			$usdeur_{-1}$	0.09 (2.98)	
							R^2	0.48	
							s	0.012	
	Model 22 Dep. var= TWI		Model 23 Dep. var= TWI						
Con	0.37 (3.49)		Con	0.39 (3.69)					
Δkki_{-1}	0.24 (3.93)		Δkki_{-1}	0.25 (4.01)					
$\Delta olje$	-0.03 (-3.38)		$\Delta olje$	-0.022 (-3.05)					
kki_{-1}	-0.094 (-3.98)		kki_{-1}	-0.08 (-3.65)					
$(i-i^*)_{-1}$	-0.088 (-2.13)		$(i-i^*)_{-1}$	-0.06 (-1.72)					
$olje_{-1}$	-0.008 (-3.43)		$olje_{-1}$	-0.004 (-2.47)					
p_{-5}	0.07 (1.91)								
p^*_{-5}	-0.06 (-1.62)								
R^2	0.16		R^2	0.14					
s	0.01		S	0.01					

All variables are in logs, except the interest rate differential. An interest rate differential equal to one percentage point is denoted as "0.01" in the data, see footnote 20 for interpretation of the coefficients.

1. Real exchange rate in Norway. Trade weighted exchange rate (TWI) deflated by relative consumer prices. January 1971 – February 2008.1971=1

Volatile, high, falling inflation   Low and stable inflasjon

Real exchange rate
Nominal exchange rate (TWI)
$P^{Trade\ part.}/P^{Norway}$

Real depreciation
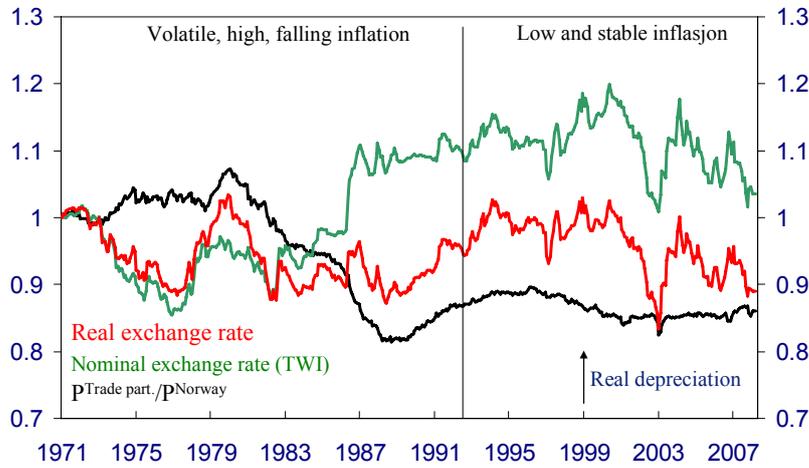
2. Inflation in Norway and among trading partners. Yearly growth in consumer prices. Monthly data. January 1971- January 2008
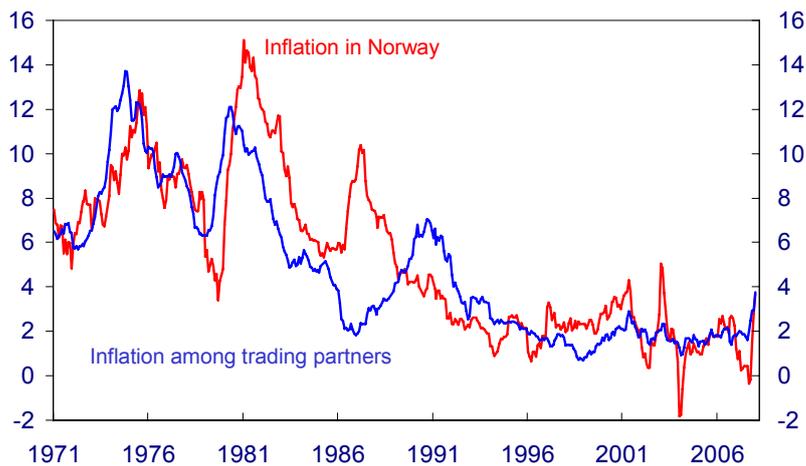
Inflation in Norway

Inflation among trading partners

3. Trade weighted exchange rate (TWI) and three-month interest rate differential relative to trading partners. January 1986 - March 2008
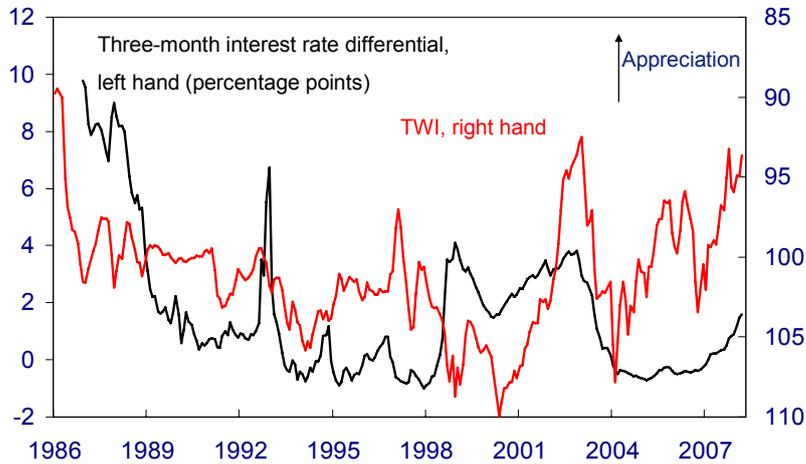
4. Trade weighted exchange rate (TWI) and three-month interest rate differential relative to trading partners. January 1999 - March 2008
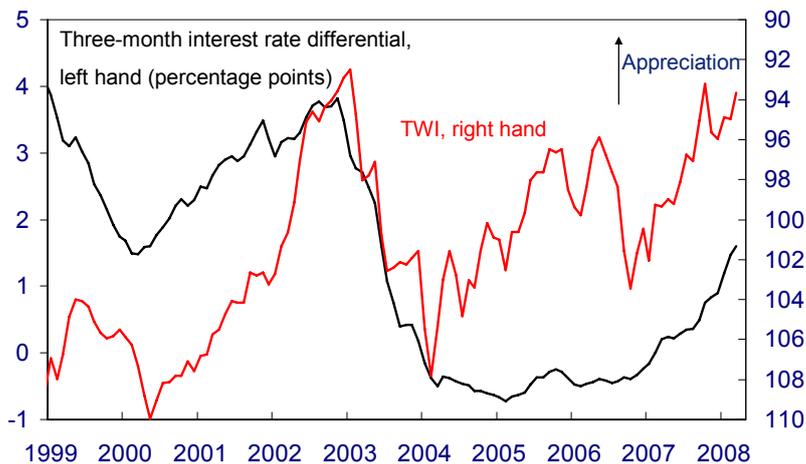
5. Twelve-month moving correlation coefficient between the change of the exchange rate (TWI) and the change of the interest rate differential relative to trading partners.[1] Monthly data. January 1987 – March 2008
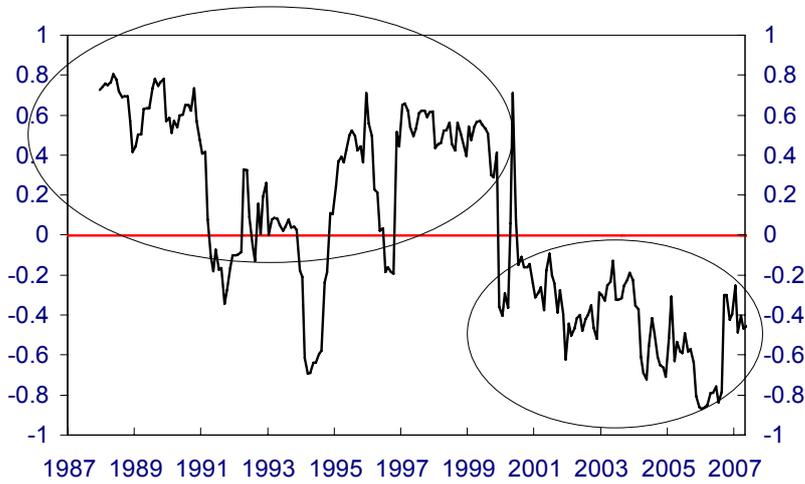
6. Trade weighted exchange rate (TWI) and the oil price in USD.
Januar 1999 - March 2008
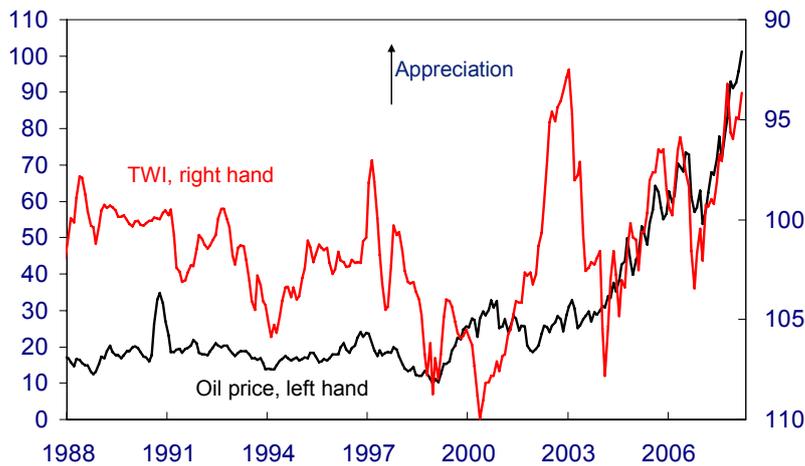
7. Trade weighted exchange rate (TWI) and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential relative to trading partners and oil price. Monthly data. January 2002 - March 2008[1]
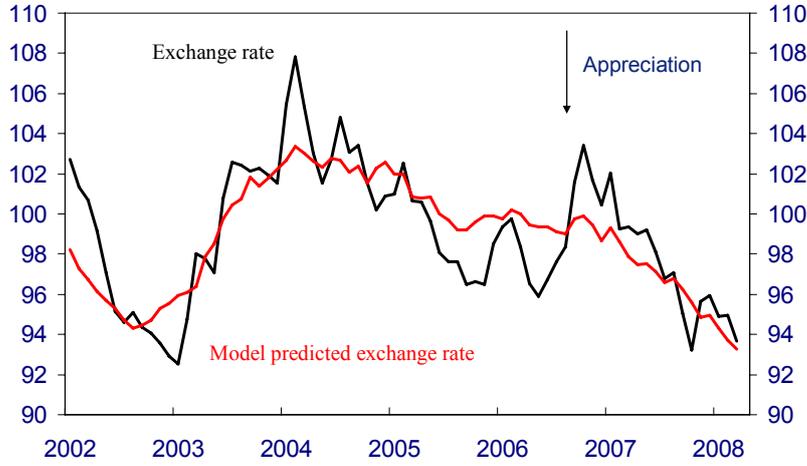
8. Trade weighted exchange rate (TWI) and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential relative to trading partners and oil price. Weekly data. 4 January 2002 - 7 March 2008
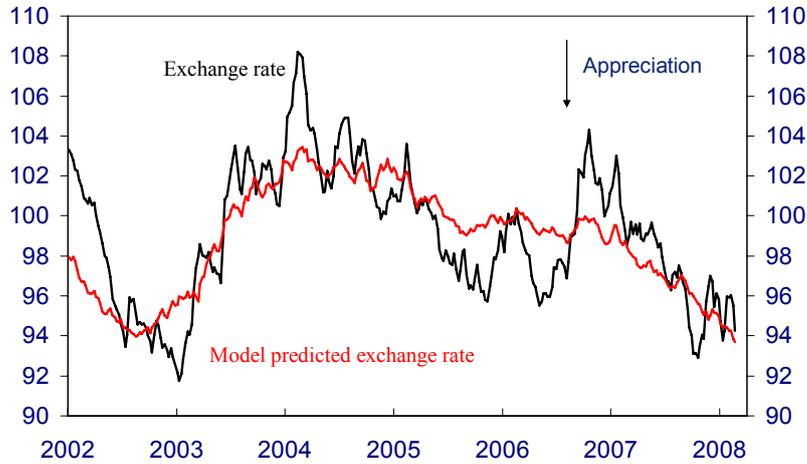
9. Trade weighted exchange rate (TWI) and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential relative to trading partners and oil price. Monthly data. January 1999 - March 2008[1]
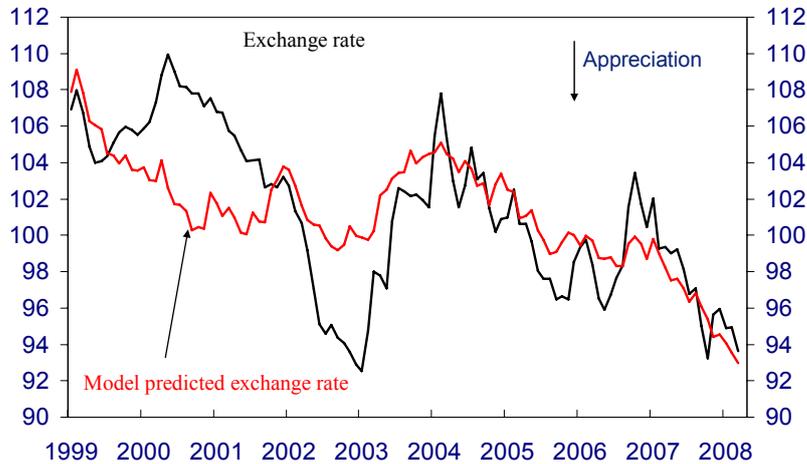
10. Nominal trade weighted (TWI) appreciation since first quarter 2004 and January 2007. Decomposition: Relative importance of the oil price and the interest rate differential as determinants of changes in the exchange rate. Calculation based on model (18)

11. Nominal trade weighted (TWI) appreciation since first quarter 2004 and January 2007. Decomposition: Relative importance of the oil price and the interest rate differential as determinants of changes in the exchange rate. Calculation based on model (20)
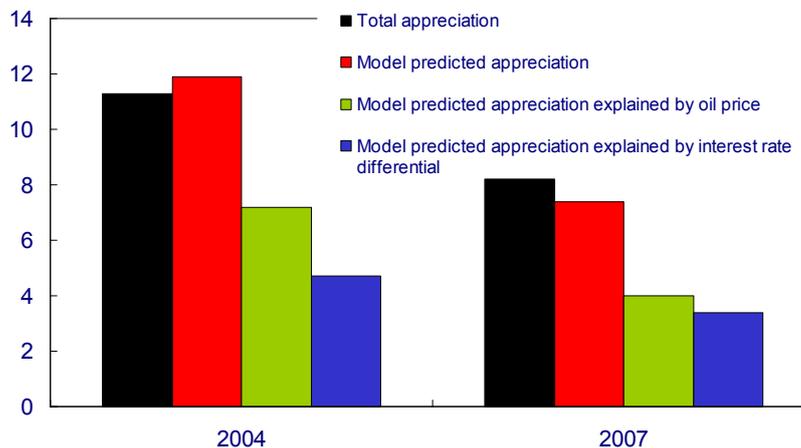
■ Total appreciation
■ Model predicted appreciation
■ Model predicted appreciation explained by oil price
■ Model predicted appreciation explained by interest rate differential
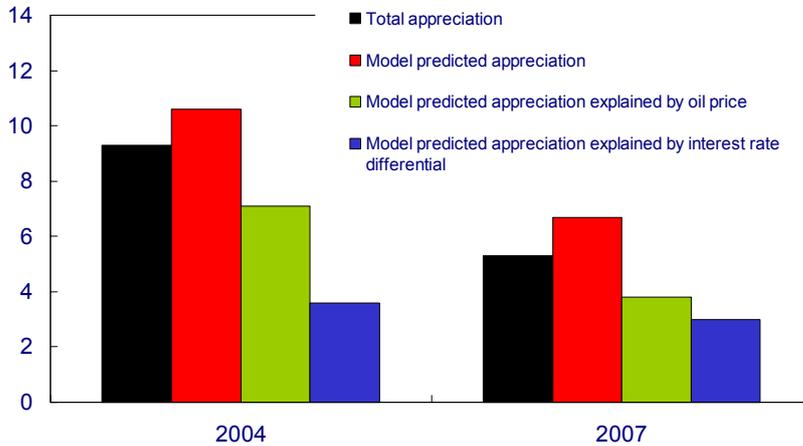
12. NOKEURO and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential relative to euro and oil price. Monthly data. January 2002 - March 2008[1]

Appreciation

Model predicted exchange rate

NOKEURO
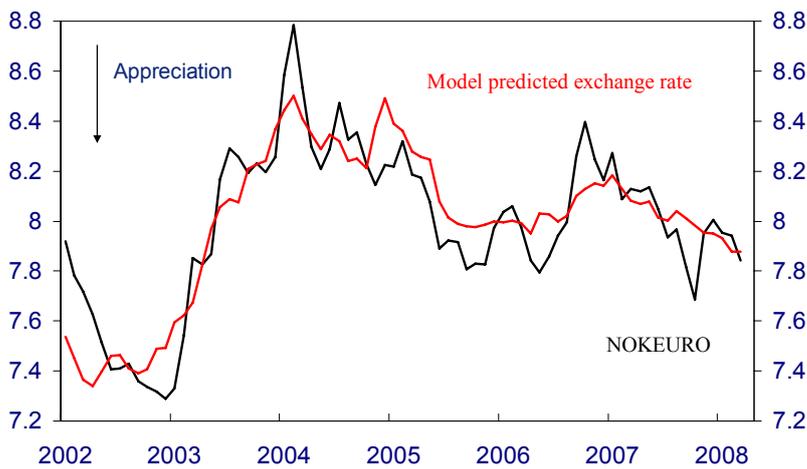
13. Trade weighted exchange rate (TWI) and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential and price differential relative to trading partners and oil price. Monthly data. January 1988 - March 2008[1]
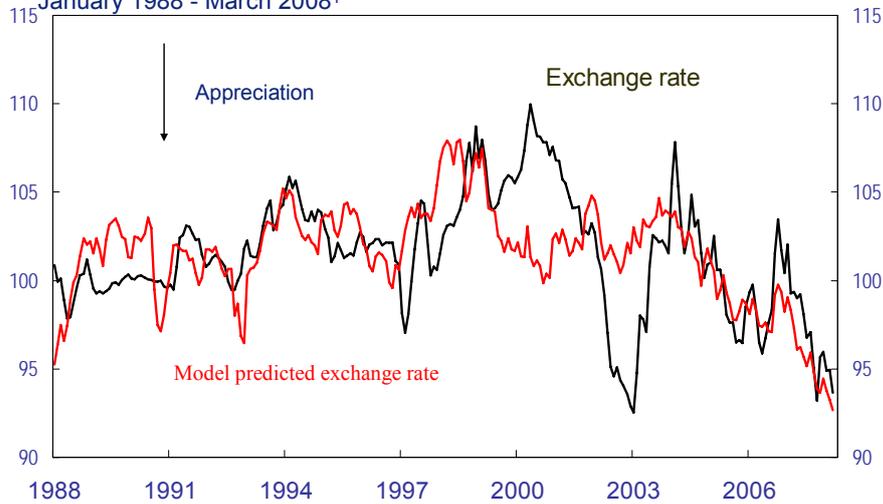
14. Trade weighted exchange rate (TWI) and model predicted exchange rate. Explanatory variables: Twelve-month interest rate differential relative to trading partners and oil price. Monthly data. January 1988 - March 2008[1]
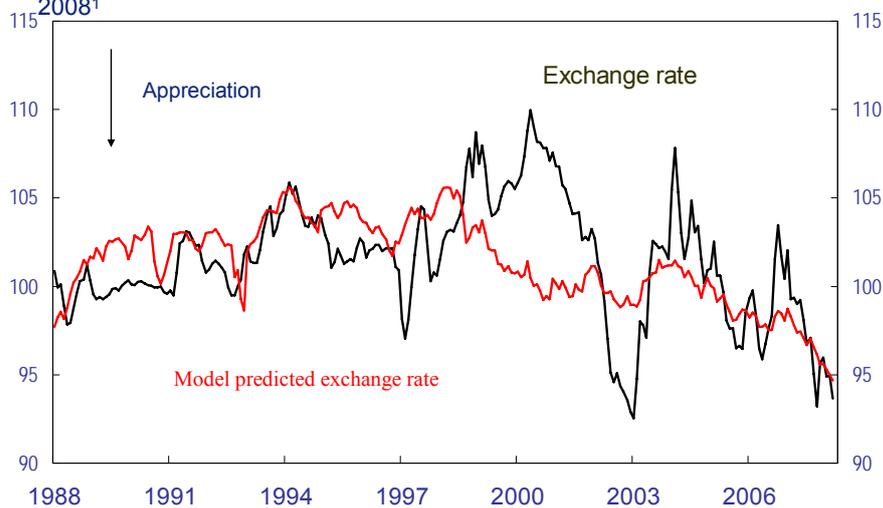
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