Bachelor's thesis

NTNU
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Interest rate differential and the krone exchange rate

An analysis of the effect of interest rate differential on the krone exchange rate

Bachelor's thesis in Economics
Supervisor: Colin Green
May 2022

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Preface

This thesis marks the end of my bachelor's degree in Economics at the faculty of Economics and Management, at NTNU. This research has above all been incredibly educational and interesting.

I wish to thank my supervisor Colin Green for good guidance throughout my working process.

Eirik Almlid

Trondheim, May 2022

Abstract

This thesis examines the relationship between the interest rate differential and the exchange rate between the Norwegian krone and euro. The study uses a multiple linear regression model with the oil price and an index for the uncertainty in the financial markets as control variables. Using time-series data of monthly observations from November 2011 to December 2022, a statistically significant relationship between the interest rate differential and the exchange rate was observed. Surprisingly, the results point to a stronger relationship than predicted in the theory of Uncovered Interest Parity. However, the results also imply that the relative effect from the interest rate differential is small, and that it can easily be overshadowed by other key factors influencing the exchange rate.

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1.Introduction

1.1 Motivation

The exchange rate is the rate at which one currency can be exchanged for another between nations or economic zones. In relation to each other it is important because of its influence on trade and capital flow dynamics. As the exchange rate is such an important macroeconomic variable in all open economies, this study was motivated by curiosity regarding how the central bank may affect the exchange rate. Substantial changes in the exchange rate may have a significant impact on both the demand and supply side of an economy. For example, in 2016, currency movements cost the British company Easy Jet around £88m, due to a fall in the pound against the dollar, which dramatically raised fuel costs (Farrell, 2016). We also know that changes in a country's currency rate have an impact on the export industries. As for Norway, fluctuations in the krone exchange rate affects the price of salmon, which is widely exported (Kunnskapsbanken for Nord-Norge, 2019). Both examples above demonstrates that the exchange rate is a key factor determining a country's economic stability. This is something that is of interest for a central bank, which aims for a stable economy.

I want to take a closer look at the Norwegian krone exchange rate in this research paper. When it comes to key determinants of the krone exchange rate - the interest rate and its differential with other countries is the only politically relevant variable, whereas factors as financial uncertainty, oil price and stock prices are all beyond the Norwegian central bank's direct control. Based on this, it became natural to write this research paper about the relationship between the interest rate differential and the krone exchange rate.

1.2 Research question

Specifically, I focus on the following research question:

"How much of the movement in the krone exchange rate can be explained by the interest rate differential?"

The thesis focuses on the exchange rate between the Norwegian krone and the euro. The euro is chosen as many of Norway's most important trading partners are located in the eurozone. Germany, the Netherlands, France, Belgium, and Spain – are all among the top 10 trading partners Norway exports the most to (Næringslivets Hovedorganisasjon, 2021). Therefore, the exchange rate between the Norwegian krone and the euro is of particular importance. In the following, when the krone exchange rate is referred to, it is the krone - euro exchange rate.

This thesis is structured as follows: Firstly, a short introduction to earlier literature is presented. Chapter two contains information about economic theory and econometric specification, where amongst other the Uncovered Interest Parity condition and the Ordinary Least Squares assumptions are presented. Chapter three presents the dataset, where the variables used in the regression analysis are included, as well as some descriptive statistics. In chapter four the regression analysis is performed, and the results are interpreted. By the end of this chapter, the Ordinary Least Squares assumptions for the model are reviewed. Lastly, chapter five contains discussion and critics with regards to the results found in the regression.

1.3 Literature review

The Norwegian Central Bank has conducted a range of research on the factors affecting the krone exchange rate. Bernhardsen and Røisland (2000) finds that, in the long term, the main factors affecting the krone exchange rate are the oil price and the price differential between Norway and other countries. In the short term, the krone exchange rate is also influenced by international financial turbulence and the interest rate differentials relative to other countries. This leads to the study only finding a significant relationship between the interest rate differential and the exchange rate in the short run (Bernhardsen & Røisland, 2000). Bernhardsen (2008) finds that in some periods the interest rate differential seems to be of more importance than the oil price and concludes that the interest rate differential and the oil price are key determinants of the krone exchange rate (Bernhardsen, 2008).

Kloster et al. (2003) decomposed the krone exchange rate and interest rate movements within the framework of Uncovered Interest Rate Parity. They looked at two periods: 1st November 2001 to 4th November 2002, and 4th November 2002 to 27th March 2003. The first period was characterized by a strengthening of the krone and an increase in the interest rate differential. The second period was characterized by a weakening of the exchange rate and a decline in the interest rate differential. In the first period they found that the interest rate differential could only explain up to half of the strengthening of the krone. In the second period, they state that the entire depreciation of the exchange rate can potentially be explained by the decline in the interest rate differential (Kloster, et al., 2003).

Naug (2003) sets up an econometric model for the exchange rate based on monthly data from January 1999 to January 2003. The model includes the effects of the oil price, the interest rate differential against other countries, developments in US stock prices and an indicator of expected variability between the major currencies. This analysis concludes that changes in the interest rate differential has the strongest effect on the krone exchange rate when stock prices have fallen and when the major currencies are expected to fluctuate less. Also, shifts in stock prices and exchange rate fluctuations abroad have a stronger effect on the krone exchange rate when the interest rate differential is high. The krone exchange rate can therefore be very volatile when Norway is in a different economic cycle than abroad (Naug, 2003).

The literature tends to agree that the interest rate differential indeed affects the exchange rate. However, there is different answers to how strongly it affects, and whether it corresponds to other variables.

2. Economic theory and econometric specifications

In this chapter, the theory of Uncovered Interest Parity is presented along with the thesis' methodological approach to answer the research question. The comprehension of the Ordinary Least Squares (OLS) approach is covered, along with relevant regression specifications and hypothesis testing.

2.1 Uncovered Interest Parity (UIP)

The Uncovered Interest Parity (UIP) condition is presented to provide a theoretical framework for interpreting our findings from the regression analysis. As seen from this theory, the research question is an indirect analysis of this UIP-condition.

The theory of UIP provides a simple relationship between the interest rate differential and the exchange rate between two currencies. It recognizes that portfolio investors at any time have the choice of holding assets denominated in domestic currency, offering the own rate of interest i_t, or of holding assets denominated in foreign currency, offering the own rate of interest i_t^F (Isard, 1996, p. 3). The hypothesis is that the expected return on an investment is the same for both currencies, in the sense that the expected change in exchange rate is equal to the interest rate differential (Holden, 2016, p. 369). *Equation 1* depicts the UIP-condition.

$$(1 + i_t) = (1 + i_t^F)\frac{E_{t+1}^e}{E_t}$$

Equation 1 – UIP-condition

The left side of the equation, $(1 + i_t)$, is the expected return on investments in domestic currency. The right side of the equation is the expected return on investments in a foreign currency. This return is equal to the interest rate offered in the foreign currency $(1 + i_t^F)$, times the expected change in exchange rate $\frac{E_{t+1}^e}{E_t}$.

We can rewrite this equation to:

$$i_t - i_t^F = \frac{E_{t+1}^e - E_t}{E_t}$$

Equation 2 – Expected change in exchange rate

This equation states that the interest rate differential gives the expected *percentage* change in exchange rate. An increased interest rate differential, indicating a higher interest rate in the domestic currency, will according to this theory lead to a reduction (appreciation) of the exchange rate in favor of the domestic currency.

This provides a theoretical basis for testing the interest rate differential further in an econometric model. It is important to emphasize that the UIP-condition describes an equilibrium relationship between the interest rate and the foreign exchange market, rather than being an expression of causality.

2.2 Ordinary Least Squares (OLS)

This study empirically examines whether there is a connection between the krone exchange rate and the interest rate differential. These will be the dependent variable and the variable of interest, respectively. As the model being set up contains two control variables, a multiple regression analysis is used. The most common regression method to estimate this is the Ordinary Least Squares (OLS). This method gives us the best line that minimizes the sum of the squared distances between the data points and the regression line. The OLS-method requires one dependent variable (Y), and one or more independent variables (x_k), plus an error term (μ). A general multiple linear regression model is presented as follows:

$$Y_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t} + \cdots + \beta_k x_{kt} + \mu_t$$

Equation 3 - OLS

Y is the dependent variable, β_0 the constant term, and x_k the explanatory variables with their respective slope coefficients β_k. The slope coefficients are the model's estimated change in the dependent variable by one unit increase in corresponding x, all else equal. The *t* denotes the time period and illustrates that we are analyzing time-series data.

The error term, μ, can be understood as standing for "unobserved". It is given as the difference between the expected value of Y, $E(Y)$, in our predicted model and the actual value of Y. It represents factors other than x that affect Y. The size of this term depends on the non-measurable factors that affects the expected value of Y. These can be factors that are not measurable, or factors that we do not have data on. The greater the value of μ, the greater the proportion of variation in the dependent variable will be explained by variables outside the model (Wooldridge, 2019, p. 21).

For the estimated results in this model to be reliable and effective, there are several assumptions that must be met. In the following, the OLS assumptions are presented.

MLR.1 – Linear in Parameters

The coefficients ($\beta's$) in the regression model are linear. Explained through *equation 3*.

MLR.2 – Random sampling

The observations should be independent of each other, meaning the values for $Y_i, x_{i2}, \ldots, x_{ik}$ should come from a random sample of n observations.

MLR.3 – Multicollinearity

In the sample, there must be enough variation between the independent variables. If one independent variable is exact linear combination of other variables, the model suffers from perfect collinearity and cannot be estimated by the OLS (Wooldridge, 2019, p. 80).

MLR.4 – Zero conditional mean

The error term, μ, has an expected value of zero given any values of the independent variables. In other words: $E(\mu|x_k) = 0$ (Wooldridge, 2019, p. 82). This assumption can be violated for instance if the functional relationship between the dependent and the independent variable is misspecified, or if important factors correlated with any of the independent variables are omitted (Wooldridge, 2019, p. 83).

Under these assumptions, *MLR.1 – MLR.4*, the OLS estimators are unbiased estimators $(\widehat{\beta_k})$ of the population parameters (β_k).

MLR.5 – Homoscedasticity

The error term, μ, has the same variance given any value of the explanatory variables. In other words: $Var(\mu|x_k) = \sigma^2$ (Wooldridge, 2019, p. 88). The opposite of homoscedasticity is called heteroskedasticity and implies that the model's prediction is better for some x-values than others, which is undesirable.

MLR.1 – MLR.5 form the *Gauss-Markov* assumptions. Under these assumptions, the estimated coefficients of the model are the best linear unbiased estimators (BLUEs). This means that there is no other linear estimator that has a lower sample variance than the current estimator.

MLR.6 – Normality

The error term, μ, is independent of the explanatory variables x_k and is normally distributed with zero mean and variance σ^2: $\mu \sim Normal(0, \sigma^2)$ (Wooldridge, 2019, p. 118).

The dataset used in this thesis contains time-series data, which means that some of the assumptions differ slightly. Therefore, I will specify one especially important assumption for time-series data, which is the assumption of *no serial correlation*.

No serial correlation

Conditional on x, the errors in the two different time periods are uncorrelated: $Corr(u_t, u_s|x) = 0$, for all $t \neq s$ (Wooldridge, 2019, p. 342). Meaning there should not be any autocorrelation in the error term. This means that the error term for an observation must be independent of the error term for another observation. The covariance between the error terms must therefore be equal to 0.

In chapter 4.4, the *MLR* assumptions will be reviewed with the model used for my regression analysis. The *No serial correlation* assumption will be further addressed in the critiques part of the thesis, in chapter 5.1.

2.3 R-squared

The R-squared (R^2) shows how much of the variance in the dependent variable that is explained by the independent variables. This measure is the ratio of the explained variation (SSE) compared to the total variation (SST); thus, it is interpreted as the *fraction of the sample variation in Y that is explained by x. Equation 4* provides the two ways of computing the R-squared. (Woolridge, 2019, p. 35).

$$R^2 = \frac{SSE}{SST} = 1 - \frac{SSR}{SST}$$

Equation 4 - R-squared

Because the SSE cannot be bigger than the SST, the value of R-squared is always between zero and one. If all the data points are on the same line, the R-squared equals 1 - indicating that the OLS line is perfectly fitted. While a R-squared nearly equal to zero indicates a poor fit.

I will also refer to a measure called adjusted R-squared. This measure takes into consideration that the R-squared increases when more variables are added to the model. The adjusted R-squared weighs the explained variance against the number of variables included in the model. (Woolridge, 2019, p. 196)

2.4 Hypothesis testing

Hypothesis testing will be utilized to determine whether our results from the OLS provides any significant information about the real population parameters. One way of interpreting the effect of certain variables is to observe the estimated coefficients *t*-statistics and *p*-values. This *t*-statistic can be used to perform a *t*-test, which is performed to test a particular hypothesis to a given degree of significance.

The procedure requires a null hypothesis (H_0) and an alternative hypothesis (H_A) that are mutually exclusively. The intention is to investigate whether there is a basis for rejecting the null hypothesis. The value we use to test against the alternative hypothesis, is called the *t*-statistic. The mathematical behind this *t*-statistic is expressed as the difference between estimated and hypothetical coefficient, divided by estimated standard deviation (Wooldridge, 2019, p. 120).

$$t_{\widehat{\beta_j}} = \frac{\widehat{\beta_j} - \beta_j}{se(\widehat{\beta_j})}$$

Equation 5 - t-statistic

There are two different approaches to interpret a coefficients significance. One called the critical value approach, and the other the *p*-value approach. The critical value approach finds the threshold *t*-statistic using a specific level of significance and number of degrees of freedom. Whether the computed *t*-statistic is within the range of rejection of our critical value, determines whether we reject or fail to reject the null hypothesis. The degree of freedom (df), with n observations and k independent variables, can be expressed as $df = n - k - 1$.

The *p*-value approach gives the *smallest* significance level at which the null hypothesis would be rejected. This value is known as the *p*-value (Woolridge, 2019, p. 130). If the significance level is 5% and the p-value of the coefficient is greater than 0.05, the coefficient is not considered statistically significant, and the effect can be interpreted as a random relationship in the sample.

In this thesis, two-tailed tests will be applied. The null hypothesis will be that the explanatory variable has no effect on the dependent variable. While the alternative hypothesis will be that the explanatory variable has either a positive or negative effect. Formally, we formulate the hypothesis as:

$$H_0: \beta_j = 0$$

$$H_A: \beta_j \neq 0$$

2.3 Standardized beta coefficients

Since statistical significance does not tell us anything about the economic magnitude of effect, I include the standardized beta coefficients to help emphasize how strong the effect of the variable of interest is. As different scales on the explanatory variables cause difficulty in interpreting the relative effect on the dependent variable, the standardized beta coefficients are a simple method to identify which of the coefficients that has the greatest relative impact on the dependent variable (Johannessen, et al., 2020, p. 354). The standardized beta can be described by *equation 6*.

$$B_1 = \beta_1 \frac{S_x}{S_Y}$$

Equation 6 - Standardized beta coefficient

In words, this states that the standardized beta coefficient (B_1) is equal the unstandardized beta coefficient (β_1), times the standard deviation of the coefficient (S_x) divided by the standard deviation of the dependent variable (S_Y). This value lies between -1 and 1, where a value closer to the end points indicates a greater importance of the relevant variable.

The interpretation of the standardized beta coefficient is that if x_1 increases by one standard deviation, then $\hat{Y}$ changes by $\widehat{B_1}$ standard deviations. Thus, we are not measuring effects in terms of the original units of Y or the x_k, but in standard deviation units. (Woolridge, 2019, p. 185).

3. Presentation of dataset

In this chapter, the data material used in the empirical analysis will be explained. The data is described using descriptive statistics and graphs that show the development in the period between 2011 – 2021.

3.1 Variables

The krone exchange rate and the interest rate differential are the dependent and the variable of interest, respectively. From previous research, there were two clear variables to include as control variables in this study. These were the oil price and an index for the uncertainty in the financial markets. The data collected for the different variables are from various sources. The period analyzed is from November 2011 to December 2021, with monthly observations of each variable. All data represent the average value of the monthly observations, except the variable for uncertainty in the financial markets, which represents the highest index value registered for each month.

In the following, I will present the multiple linear regression model used for this analysis, and an explanation of each variable. The regression model that is set up is in log-level terms, meaning the dependent variable will be expressed in logarithmic term. This will give us the percentage change in the dependent variable, with a unit change in our independent variables. This is done for more logical interpretation of our regression results. The logarithmic term of the dependent variable is denoted as log_E. In this section, however, I will present the descriptive statistics in level terms for the dependent variable, as this allow for more descriptive information. *Equation 7* depicts the regression model that is set up.

$$log\_E = \beta_0 + \beta_1 IRDifferential + \beta_2 OilPrice + \beta_3 VIX + \mu$$

Equation 7 - The regression model

Table 1 provides a short description of the variables of the model, followed by an explanation of each variable.

Variable	Description	Source
E	Average monthly nominal exchange rate. NOK/euro.	The Norwegian Central Bank
IRDifferential	The percentage point differential between the NOWA and the EIONIA interest rate. NOWA – EIONIA.	The Norwegian and Finnish Central Bank
OilPrice	The average monthly price on Brent Crude in USD per barrel.	Oljedirektoratet
VIX	Highest registered VIX-index for each month.	finance.yahoo.com

Table 1 – Variables

Dependent variable – E

The dependent variable is the nominal exchange rate between the Norwegian krone and the euro. This value represents how the Norwegian krone is valued relative to the euro. An increase in this variable represents a depreciation of the krone, and an appreciation of the euro. The same reasoning holds the other way around, a decrease of E, represents an appreciation of the krone and a depreciation of the euro.

The data collected represents the average monthly exchange rate and is collected from the Norwegian central bank's web site (Norges Bank, 2022).

Variable of interest - IRDifferential

The variable *IRDifferential* is the differential between the Norwegian NOWA (Norwegian Overnight Weighted Average) interest rate and the european EONIA (euro OverNight Index Average) interest rate. NOWA is the interest rate on unsecured overnight loans in Norwegian kroner between banks that are active in the Norwegian overnight market. NOWA is based on actual transactions reported via the Norwegian central bank's money market reporting (Norges Bank, 2022). The corresponding interest rate in the eurozone is the EONIA rate. This is the value-weighted average interest rate on eurozone interbank overnight loans (Kenton, 2022). The variable *IRDifferential* gives the percentage point difference in interest rate between NOWA and EONIA. A higher value of *IRDifferential*, represents an increased difference between the two interest rates, in favor of Norway (NOWA). Meaning if Norway increases its interest rate compared to the eurozone, we will have an increase in the variable *IRDifferential*.

Data on the monthly average NOWA interest rate is collected from the Norwegian central bank's website (Norges Bank, 2022). Data on the monthly average EONIA interest rate is collected from the Finnish central bank's website (Suomenpankki, 2022).

Control variable - OilPrice

The oil price is particularly relevant in an analysis of the krone exchange rate, as the petroleum industry in Norway exceeds half of the total value of Norwegian exports of goods. This makes oil the most important export commodity in the Norwegian economy (Norsk Petroleum, 2022). Previous research has found that the krone exchange rate is highly affected by changes in the oil price, both in the short and long run (Bernhardsen & Røisland, 2000). This makes the oil price the most important control variable in this analysis, as it is the factor which may have the clearest impact on the krone exchange rate.

The variable in my dataset includes the monthly average price on Brent Crude in US Dollar (USD) per barrel. Data is collected through norskpetroleum.no, which have Oljedirektoratet as source (Norsk Petroleum, 2021).

Control variable – VIX

This variable is included to measure the effect of uncertainty in the financial markets on the krone exchange rate. The Norwegian krone is often perceived as a small and peripheral currency, and in the event of greater uncertainty in the markets, the krone is expected to notice the effect of investors escaping to "safer" currencies (Flatner, 2009).

The index used for financial uncertainty in this analysis is the CBOE Volatility Index. It is listed on the Chicago Board Options Exchange (CBOE) and is widely reposted as the benchmark of volatility in the stock market. It is known as the "fear gauge", as it indicates the expected level of uncertainty. Higher index suggests more expected uncertainty being priced into the marketplace, while lower index values suggest less expected uncertainty. It was initially designed to measure market expectations according to 30-day volatility in the S&P 100 index's option prices. In 2003, VIX was updated to follow options on the S&P 500 index instead - which is the main index for US equities today (CBOE, 2022).

This variable represents the highest registered value of the VIX (Volatility Index) index per month. Data on the VIX index is collected through the finance site on yahoo.com (yahoo!, 2022).

3.2 Descriptive statistics

This section provides descriptive statistics of the data collected. I have included the NOWA and EONIA variables in this section, as they provide insight into the interest rate levels for the two areas of interest in this analysis. *Table 2* shows the central tendencies for all the variables in the model.

Variable	Obs	Mean	Std. Dev.	Min	Max
E	122	9.131	1.018	7.324	11.343
IRDifferential	122	1.091	.381	.458	1.986
NOWA	122	.899	.573	-.01	2.25
EONIA	122	-.191	.279	-.492	.79
OilPrice	122	72.343	26.389	18.38	125.45
VIX	122	23.641	10.607	12.89	85.47

Table 2 - Descriptive statistics

From this table, we notice that our dependent variable, E, exhibits quite large variation, with the strongest value of 7.324 and the weakest value of 11.343. The mean exchange rate lays around the middle of the maximum and the minimum value, at 9.131. There is a high variance, represented with a standard deviation of 1.018. *Figure* 1 illustrates the development of the exchange rate over our years of data. From this, we can clearly see that the krone exchange rate has weakened over the 10-year period. The lowest value (strongest krone) was registered early in our period of interest, in August in 2012. While the highest value (weakest krone) was observed under the corona pandemic in April 2020.

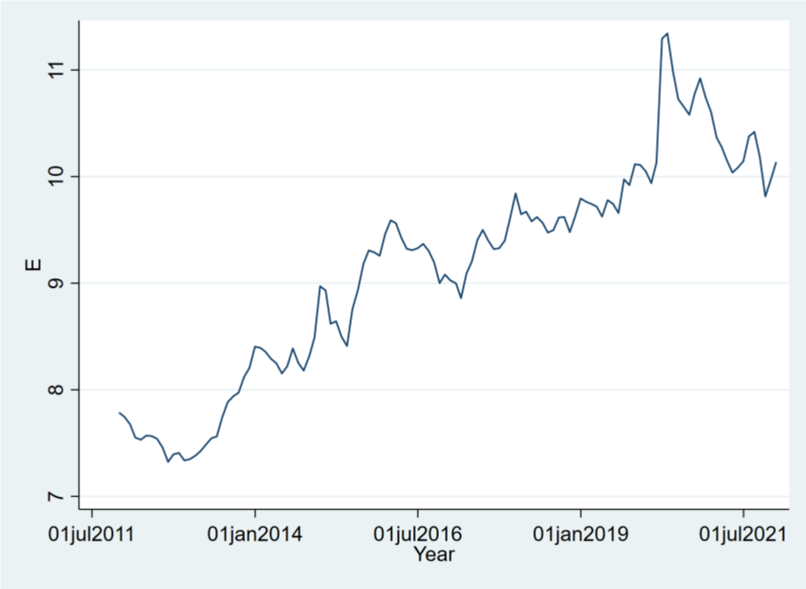

Figure 1 – Development of the krone exchange rate

Furthermore, *table 2* shows that our variable of interest, *IRDifferential*, only have positive values in our dataset. Indicating that the interest rate differential has been positive, and in favor of Norway, the whole 10-year period. We notice that the mean interest rate differential between Norway and the eurozone is little above 1, meaning that Norway has, on average over the last 10 years, had a whole percentage point higher interbank interest rate than the eurozone. The distributions of the two interest rates are illustrated by *figure* 2. We observe an abnormal downfall in the NOWA interest rate in the start of 2020. This was due to the corona pandemic, which reduced the interest rate to almost zero percent. Since the EIONIA interest rate was already negative, it didn't change as much, making the differential between the two interest rates substantially smaller.

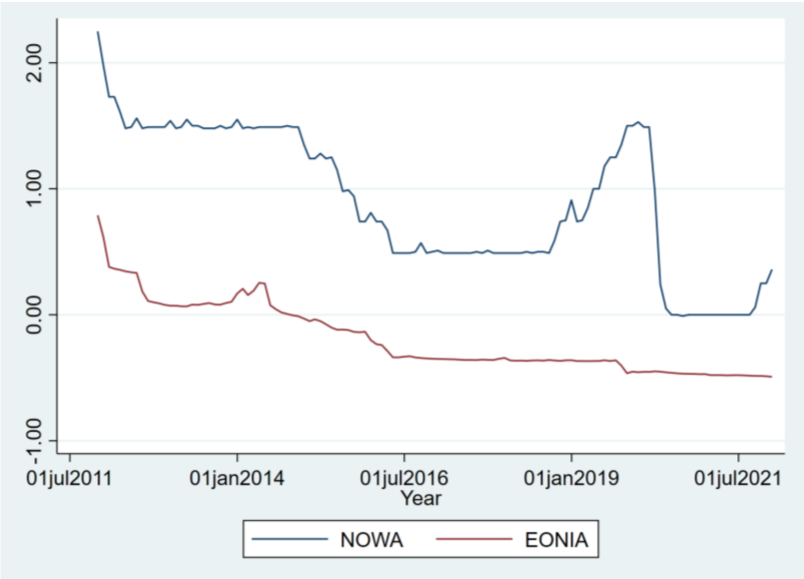

Figure 2 - NOWA and EIONIA

The oil price has relatively high variations in our observations, with a minimum value of 18.38 and a maximum value of 125.45. This indicates high fluctuations in the oil price over the 10-year period, which is expected as the data contains times of both strong international economic development from 2011 to 2015 and times of the corona pandemic from 2019 to 2021. This could possibly explain the standard deviation of 26.389. The mean oil price of the period is 72.343 dollar per barrel.

The VIX index has a minimum and maximum value of 12.89 and 85.47, respectively. Even though the mean of 23.641 is quite low, the index has clear spikes represented with the maximum value of 85.47. This value was registered in the start of the corona pandemic and represents the high uncertainty in the market at the time.

4. Regression analysis

From the UIP theory presented, we expect to see a lower exchange rate when the interest rate differential increases. This means that the krone exchange rate appreciates when the differential increases in favor of Norway. In this part of the thesis, a multiple linear regression will be estimated to detect if our assumptions from the UIP theory are correct. The program used to perform the analyzes are the statistical tool STATA.

4.1 The model

When we read about exchange rate movements, changes are often expressed in percentage. Therefore, in order to get a more intuitive interpretation of our model, the logarithmic term on the dependent variable, *E*, is used. All independent variables in the model are in level terms, which means we will set up a log-level model. Through a multiple linear regression model, the control variables will partial out the effects of these variables on the krone exchange rate, allowing us to gain a better understanding of how the variable of interest, *IRDifferential*, affects the krone exchange rate. When examining the effect of an independent variable on the dependent variable, the control variables are kept constant. In the following, the regression analysis is performed.

Table 3 provides the output of the regression analysis. I have included three models in this table, where I have added the independent variables step-by-step. The three models run the following regressions:

(1) $\log\_E = \beta_0 + \beta_1 IRDifferential$

(2) $\log\_E = \beta_0 + \beta_1 IRDifferential + \beta_2 OilPrice$

(3) $\log\_E = \beta_0 + \beta_1 IRDifferential + \beta_2 OilPrice + \beta_3 VIX$

Variables	(1) log_E	(2) log_E	(3) log_E
IRDifferential	-0.156***	-0.0535**	-0.0510**
	(0.0233)	(0.0180)	(0.0173)
OilPrice		-0.00309***	-0.00285***
		(0.000259)	(0.000261)
VIX			0.00185**
			(0.000581)
Constant	2.376***	2.487***	2.424***
	(0.0269)	(0.0205)	(0.0281)
N	122	122	122
adj. R^2	0.267	0.663	0.687

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3 - Multiple linear regression analysis

The statistical significance level of the variables is indicated by stars (*) next to the numbers. The more stars a variable has, the greater the certainty that the variable is not the consequence of a random relation in the sample. The models adjusted R-squared, along with the number of observations, are appended at the bottom of the table. From the adjusted R-squared, we can clearly see that our three independent variables have a considerable role in explaining the exchange rate movements. Observing the differences between the models, we can see that the oil price has a noteworthy effect as it both raises the adjusted R-squared dramatically and partials out a significant effect for the *IRDifferential* variable - lowering the coefficient from 0,156 in *model 1* to -0,0535 in *model 2*. The *VIX* variable increases the adjusted R-squared from 66.3% to 68.7% and partial out some effect for our variable of interest. In the following interpretation of the results, I will focus on *model 3*. The output from this model gives us the following OLS regression line:

$$\widehat{log\_E} = 2.424 + (-0.0510)IRDifferential + (-0.00285)OilPrice + 0.00185VIX$$

We have a regression constant of 2.424, meaning if all our independent variables are equal to 0, we will have a natural logarithm of the exchange rate equal to 2.424. This has no economic interpretation as having an oil price and VIX-index equal to zero would be unrealistic.

For our variable of interest, *IRDifferential,* we get a coefficient of -0.0510. The interpretation of this is that of every unit increase in the interest rate differential, the exchange rate will decrease (appreciate) 5.10%, all else equal. Meaning if Norway increases its interest rate by a whole percentage point, and the interest rate in the eurozone is unchanged, we could expect a monthly appreciation of 5.10% of the krone exchange rate. This may initially sound like a noteworthy impact on the exchange rate. However, we rarely witness such a huge increase in interest rates on a monthly perspective. So, we could interpret this coefficient with a 0.25 unit increase in *IRDifferential* also. Indicating a change in interest rate differential equal to 0.25, which gives us a greater understanding of the impact. This would lead to a reduction (appreciation) in the krone exchange rate of 1.275%, all else equal, which is not particularly high considering a standard deviation of 1.018. Regardless of this, we have a significant negative coefficient, illustrated with the two stars (**), which implies that there is a clear relationship between the interest rate differential and the krone exchange rate.

We can also observe that our control variable, *OilPrice,* has a negative coefficient of -0.00285. The interpretation of this is that a one dollar increase in the oil price will lead to a decrease (appreciation) in the krone exchange rate of 0.285%. The negative coefficient confirms the initial prediction regarding the impact of the oil price on the Norwegian economy and the krone. This indicates a stronger krone when the oil price increases. As seen from our descriptive statistics section, in *table 2*, the oil price can fluctuate much more than a dollar or two in a monthly perspective. Only a dollar change in the oil price is less frequently seen than the opposite. Therefore, we can get a greater understanding of the impact of the oil price through a change of for example 10 dollars. Then the exchange rate is expected to appreciate with 2.85%.

For our second control variable, *VIX,* we have a positive coefficient of 0.00185. This positive coefficient implies that increased uncertainty in the financial markets, increases (depreciates) the krone exchange rate. Our initial assumption regarding the krone being a peripheral currency in times of high uncertainty is confirmed by this positive coefficient. The interpretation of this is that for every unit increase in the volatility index, the krone exchange rate is expected to increase (depreciate) by 0.185%, all else equal. From this we can understand that spikes in the market uncertainty, which is symbolized by a substantial higher VIX-index, will have clear impacts on the krone exchange rate.

It is also worth mentioning the adjusted R-squared value of this model. An adjusted R-squared equal to 0.687 means that our explanatory variables account for 68.7% of the fluctuations in the krone exchange rate in our period from November 2011 to December 2021.

To confirm if the result of the variable *IRDifferential* is reliable, a *t*-test can be performed. We have the following hypotheses:

$H_0: \beta_{IRDifferential} = 0$

$H_A: \beta_{IRDifferential} \neq 0$

The test statistic:

$$t_{\widehat{\beta_j}} = \frac{\widehat{\beta_j} - \beta_j}{se(\widehat{\beta_j})}$$

$$t = \frac{-0.0510 - 0}{0.0173} = -2.95$$

With a 5% significance level and 118 (122 – 3 – 1) degrees of freedom, the rejection region is everything beyond the critical value of -1.96 – 1.96. We observe a test statistic of -2.95 and can conclude that the null hypothesis is rejected. This indicates that the interest rate differential indeed has a significant impact on the krone exchange rate. This can also be confirmed by looking at the *p*-value for our variable *IRDifferential.* From the STATA output, a *p*-value of 0.004 is observed. This is less than our significance level of 5%, indicating the same conclusion as the critical value approach. The *p*-value of 0.004 is the reason the coefficient of the variable *IRDifferential* is labeled with two stars (**) in *table 3*. We accept that there is a 0.4% chance of committing a Type I error. For the variable *OilPrice,* the chance of committing a Type I error is under 0.1%, and therefore three stars (***) are labeled.

4.2 How much can be explained by the variable of interest

Until now, we have demonstrated that the interest rate differential has a statistically significant effect on the krone exchange rate. This, however, doesn't provide a good answer to the question of "how much" the interest rate differential relatively impact the exchange rate. As our three explanatory variables have different scales, it is hard to interpret the relative effect from our unstandardized coefficients from *table 3*. An increase of a whole unit in the variable *IRDifferential* is more drastic than an increase of one dollar in the *OilPrice,* or a unit higher *VIX,* for example. A way of getting an insight on the relative level of impact, is to look at the standardized beta coefficients of our multiple regression model. In this way, we can see which of the variables included that affects the exchange rate the most, through the variables relative impact. *Table 4* provides the standardized beta coefficients.

	Coefficient	Standardized beta coefficient
IRDifferential	-0.0510**	-0.1707
OilPrice	-0.00285***	-0.6617
VIX	0.00185**	0.1725
Constant	2.424***	

Table 4 - Standardized beta coefficients

This allows us to rank the coefficients by absolute value. The interpretation of these standardized beta coefficients is that a unit increase in the standard deviation of the independent variable, changes the standard deviation for the dependent variable equal to the value of the standardized beta coefficients. For example, for *IRDifferential*, a change in the standard deviation of 1, would change the standard deviation of *log_*E of -0.1707. From this, we now have the same unit of measurement for our explanatory variables. We can observe that among our explanatory variables, *IRDifferential* has the lowest relative impact on the krone exchange rate, just below the *VIX* index. The oil price has the clearest impact on the exchange rate with a standardized beta coefficient of -0.6617. This means that a change in standard deviation of 1 in *OilPrice*, changes the standard deviation of *log_E* by -0.6617. In the discussion chapter, the limitations of using the standardized beta coefficients will be discussed.

4.3 Results

In this section, an overview of the results from the preceding chapters is offered.

From the regression analysis, we found a statistically significant negative coefficient for the variable of interest, *IRDifferential*. We identified that a unit increase in this variable would strengthen the krone exchange rate of 5.10%. We then performed a *t*-test where the null hypothesis was rejected with a p-value of 0.004, indicating that the interest rate differential does indeed have a substantial effect on the krone exchange rate. For the control variables *OilPrice* and *VIX*, we observe a negative and a positive coefficient, respectively. All these answers are intuitive from our assumptions from the UIP theory and what we know from previous research. From the UIP theory, we expected a stronger krone when the interest rate increases in favor of Norway, as investors will have stronger incentives to place their money in Norwegian kroner as the return is greater. Also, an increased oil price has positive impact on expectations regarding the Norwegian economy, which affects the exchange rate to appreciate. We also know from previous research that increased uncertainty in the financial markets may weaken the krone exchange rate due to investors wanting to sit on more “stabile and safe” currencies in times of uncertainty[1].

To determine the relative effect of the *IRDifferential,* the standardized beta coefficients was presented. The standardized beta coefficient for *IRDifferential* was -0.1707. From this we can state that the relative effect of the interest rate differential is substantially lower than the effect from *OilPrice,* which had a standardized beta coefficient of -0.6617. We could conclude that the effect on the krone exchange rate is approximately the same from the interest rate differential as the effect from the *VIX* variable, which had a standardized beta coefficient of 0.1725.

4.4 OLS-assumptions control

In this chapter, I will evaluate the key assumptions for the OLS-method to the regression model presented. This will be done to examine the validity of the results, which determines if we can draw conclusions outside the model. The assumptions presented in chapter 2.2 is applied here.

MLR.1 – Linear in Parameters

The first assumption was that the relationship in the sample must be linear. To examine this assumption, we can add the quadratic terms for our explanatory variables. This means that we can see if the effect from x_k changes when it increases. If that is the case, there is some non-linear relationship between the dependent and the independent variable (Ringdal & Wiborg, 2017, p. 128). *Table 5* provides the quadratic terms for every independent variable, denoted as *IRDifferential2, OilPrice2* and *VIX2.* With these we can test whether there is some non-linearity in our variables. The hypothesis test is given as follows:

$H_0: Variable\ is\ linear$

$H_A: Variable\ is\ non-linear$

$H_0: \beta_1 = 0, \beta_2 = 0, \beta_3 = 0$

$H_A: \beta_1 \neq 0, \beta_2 \neq 0, \beta_3 \neq 0$

[1] This is also known as “flight to quality”, which occurs when investors shift their asset allocation away from riskier investments and into safer ones in times of uncertainty.

	(1)
	log_E
IRDifferential	-0.532***
	(0.0619)
OilPrice	0.00429***
	(0.00117)
VIX	-0.000995
	(0.00138)
IRDifferential2	0.206***
	(0.0262)
OilPrice2	-0.0000429***
	(0.00000736)
VIX2	0.0000425*
	(0.0000175)
Constant	2.450***
	(0.0649)
N	122
adj. R^2	0.843

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 - MLR.1 control

From this table, we can read the results of the hypothesis test through the significance levels provided in stars (*). From these we see that for all our explanatory variables, the null hypothesis can be rejected at a 95% confidence level. This means that there is observed some non-linearity in all of the variables. These results indicates that the model has some problems regarding this *MLR.1* assumption. A way of solving this issue would be to keep the squared terms in the model, making it closer to the true population.

In conclusion, there is observed some non-linearity in our variables, invalidating this assumption for our model. This can lead to certain inaccurate population estimations. In chapter 5.1, about the critique of the model, this will be discussed in greater detail.

MLR.2 – Random sampling

This assumption stated that the data collected must be a random sample drawn from the population. For times-series data, this condition will likely not be met. Time-series data differs from cross-sectional data on this area, as it studies the same variables over time. This means that the sample cannot be randomly drawn as there is a natural temporal order of the findings. The observations will not be independent of each other, because an observation of a variable today will often depend on previous observations of the same variable. Through certain corrections, time-series data can still be used in econometric analyzes. Among other things, it is important to achieve stationarity. A stationary time-series process is one in which the probability distributions are stable over time in the following sense: If we take any collection of random variables in the sequence and then shift that sequence ahead *h* time periods, the joint probability distribution must remain unchanged (Woolridge, 2019, p. 367). This will not be further examined in this thesis.

MLR.3 – Multicollinearity

There should not be observed high levels of multicollinearity. This is the degree of linear relationship between two or more explanatory variables. The assumption allows for some correlation, but the variables cannot be *perfectly* correlated. If this happens, there might be problems with multicollinearity in our model. With perfect collinearity between variables, it will be impossible to obtain unique estimates on the regression coefficients because all combinations will work the same (Wooldridge, 2019, p. 81). The problem with multicollinearity is that it increases the standard error of the parameter estimates, which again will affect the *t*-statistic. This makes generalization of our results problematic. To examine multicollinearity, a correlation analysis can be performed to look for bivariate connections in the dataset. *Table 6* shows the correlation matrix.

Variables	(1)	(2)	(3)	(4)
(1) *log_E*	1.000			
(2) *IRDifferential*	-0.522	1.000		
(3) *OilPrice*	-0.803	0.479	1.000	
(4) *VIX*	0.434	-0.201	-0.343	1.000

Table 6 - Correlation matrix

The threshold value for multicollinearity is known to be around 0.9 (Wooldridge, 2019, p. 90). From *table 6* there are no values close to this threshold level, indicating that there are no signs of multicollinearity in our model. We see that the highest correlation is found between the variables *IRDifferential* and *OilPrice*, at a correlation value of 0.479. To confirm the finding of the correlation matrix, the *variance inflation factor* (VIF) can also be examined. This VIF value will indicate if a variable has a linear relationship with other variables in the model. *Table 7* shows the VIF values.

	VIF	1/VIF
OilPrice	1.415	.707
IRDifferential	1.301	.769
VIX	1.136	.88
Mean VIF	1.284	

Table 7 - Variance inflation factor (VIF)

The table sorts the VIF values from highest to lowest, and shows no values above 10, which is looked at as the threshold value for multicollinearity (Wooldridge, 2019, p. 92). I thus conclude that there are no significant problems related to multicollinearity in my dataset, and that the *MLR.3* assumption holds.

These assumptions above are model- and variable-specific. The forthcoming assumptions concern the error term. In order to test these assumptions, we use the residuals in the sample to determine whether these assumptions hold (Johannessen, et al., 2020, p. 399).

MLR.4 – Zero conditional mean

This assumption stated that there should not be any correlation between the error term, μ, and the explanatory variables. If an important factor that is associated with any of x_k is left out, or if a variable is included erroneously, this assumption may fail. This causes bias due to an omitted variable, which is referred to as omitted variable bias (Wooldridge, 2019, p. 84). This is an untestable assumption.

MLR.5 – Homoscedasticity

This assumption stated that the variance of the residuals should be equal across all observations. Homoscedasticity is another word for "equal variability". If this assumption doesn't hold, the OLS-method might give inaccurate estimates of the standard deviations of the coefficients, which have consequences for statistical generalization (Wooldridge, 2019, pp. 88–90).

To control for this assumption, we can look at the distribution of the residuals against our fitted values. *Figure 3* provides this.

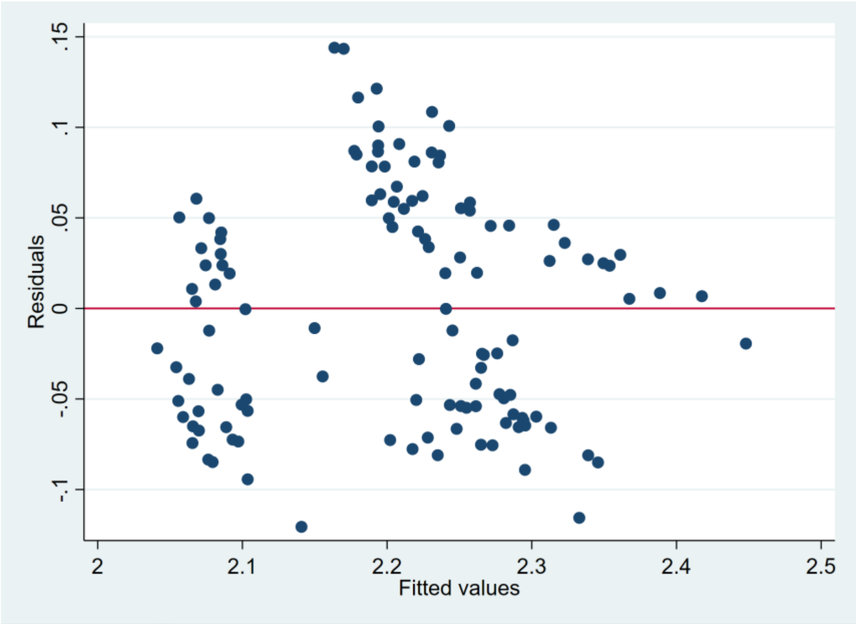

Figure 3 - Residuals against fitted values

This scatter plot suggests equal variation across the different observations. From this figure, there is no reason to believe that this assumption doesn't hold. To control our visual inspection, we can perform a formal test called Breusch-Pagan (Woolridge, 2019, p. 217), which tests if the variance in the error term is dependent on the values of the independent variables.

The Breusch-Pagan test for heteroskedasticity:

Variable: Fitted values of $log\ \_E$

H_0: $Constant\ variance\ among\ the\ residuals\ (Homoscedasticity\ is\ present)$

H_A: $Heteroscedasticity\ is\ present$

$chi2(1) = 0.14$

$Prob > chi2 = 0.7077$

From the test, we can observe that the chi-square test statistic is 0.14 and the *p*-value is 0.7077. Since the *p-value* is greater than 0.05, the conclusion is that we fail to reject the null hypothesis, indicating constant variance among the residuals, and the *MLR.5* assumption holds.

MLR.6 – Normality

This assumption stated that the error term should be normally distributed. This is the most restrictive assumption, as it includes both the *MLR.4* and *MLR.5* (Woolridge, 2019, p. 118). To control for this assumption, we can first make a visual inspection of the distribution of the residuals. *Figure 4* provides this.

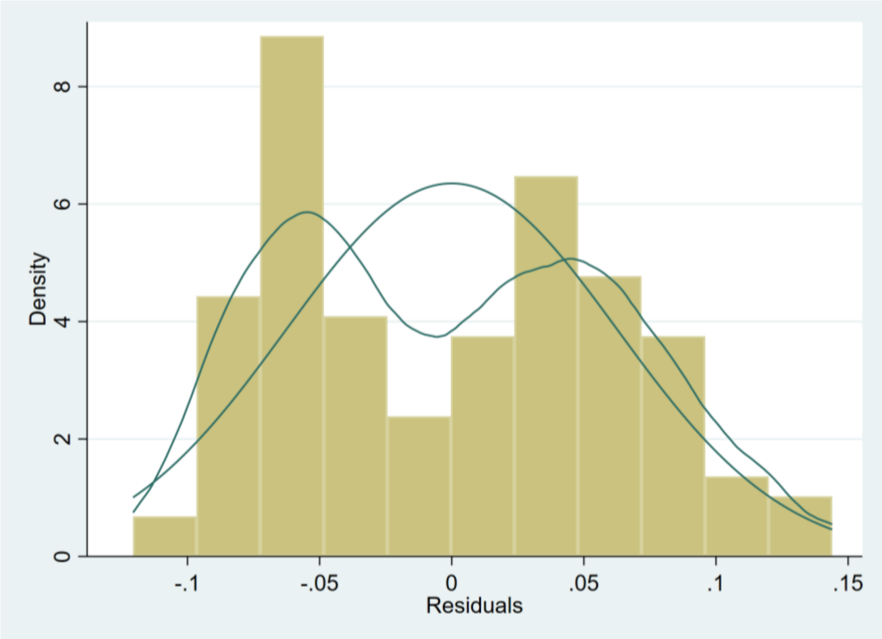

Figure 4 - Distribution of the residuals

This figure both includes the normal density plot and the kernel density plot. We see that the kernel density plot of our residuals deviates from the normal density plot, and there are reasons to believe that the *MLR.6* assumption doesn't hold. To control for this visual inspection, there is several formal tests that can be applied. One of these is called the Jarque-Bera normality test (Gel & Gastwirth, 2008). This is a simple test that uses sample estimated skewness and kurtosis to arrive at a test statistic that can be used to assess the normality.

The Jarque-Bera test for normality:

H_0: *The residuals are normally distributed.*

H_A: *The residuals does not come from a normal distribution.*

$chi(2) = 6.175$

$Prob > chi = 0.0456$

We observe a *p*-value of 0.0456, which means that the highest significance level we are allowed to use is 4.56%. This is under the 5% significance level used for this thesis, and we reject the null hypothesis. This confirms the inspection of *figure 4.*

The issue of rejecting the null hypothesis here is that the *t*-statistics obtained from our regression analysis might be a bit more inaccurate. Meaning our significance tests might be influenced. From the presentation of the OLS assumptions, from chapter 2.2, we know that this assumption plays no role in the unbiasedness of OLS, nor does is affect the conclusion that OLS is the best linear unbiased estimator under the *Gauss-markov* assumptions. But as mentioned, exact inference based on the *t*-statistics requires *MLR.6* to hold. However, this does not mean we must abandon the *t*-statistics for determining which variables are statistically significant (Woolridge, 2019, p. 169). Even though the normality assumption does not hold, we can use the central limit theorem to conclude that the OLS estimators satisfy asymptotic normality, which means that if you have a big enough sample size, you don't care that much if you reject the null hypothesis of the Jarque-Bera normality test. The central limit theorem states that the error term will be normally distributed when the sample size is large. This is because the error term consists of many different additive variables, all of which affect our dependent variable different and additive. Many such variables that work additively and separately will, according to the central limit theorem, give normal distribution

In my analysis, there is many factors that are not included, and these might have an impact on the dependent variable. Even though these are not included in the analysis, I assume that these variables, according to the central limit theorem, affects this variable additive and separate.

5. Discussion and conclusion

This research used the Uncovered Interest Parity condition as a theoretical framework. This provides a framework to look at possible opportunities for central banks to influence future exchange rates. To see these results from a central bank's perspective, it is appropriate to emphasize that the UIP theory essentially holds. In fact, we find a stronger link between the interest rate differential and the exchange rate than predicted in the UIP-theory. According to the UIP-theory, a whole percentage point change in interest rate differential should affect the future exchange rate by the exact same percentage point. In this thesis, we find that a whole percentage point increase affects the exchange rate by 5.10%. This is interesting as it indicates a stronger relationship than expected. However, the interest rate differential can to a small extent be directly used to influence the exchange rate, as it is influenced by so many other external variables. As found in this research, the oil price affects the Norwegian exchange rate to a much greater extent than the interest rate differential. This means that changes in uncontrollable variables for the central bank, such as oil price and uncertainty in the financial markets, could exceed the effects of the interest rate differential. Which makes it difficult to control the exchange rate from a central banks point of view.

Furthermore, the findings are consistent with the majority of past research. As Bernhardsen (2008) also concludes, our results indicates that the oil price and the interest rate differential are key determinants of the krone exchange rate. From our second model in *table 3*, these two variables alone had an adjusted R-squared of 66.3% with statistically significant coefficients. This suggests that the variables are noteworthy determinants of the krone exchange rate. This is also aligned with the findings from Bernhardsen and Røisland (2000), which imply a strong relationship between the interest rate differential and the krone exchange rate in the short term. However, as Bernhardsen (2008) concludes, our findings do not reveal whether the interest rate differential have had a greater impact than the oil price in some periods of our time of observation. This could be an interesting subject for future research, along with an analysis of Bernhardsen and Røisland's (2000) long-term findings on the effect of different interest rate differentials on the krone exchange rate.

On basis of this, further research is necessary to provide some more advanced understanding about the dynamics between the two variables of interest. Further studies may benefit from taking a closer look at whether there is a certain value of the interest rate differential that is of more importance than others. This would give answer on whether there is a specific range of interest rate differential that affects the krone exchange rate more than others. There are reasons to believe that, as we found some non-linearities in our *IRDifferential* variable. In addition, as both stated in this article by Ekeseth (2019), and Naug (2003), there may be a certain amount of differential that has a higher impact than others (Ekeseth, 2019).

5.1 Critique and remarks for further research

This research has several limitations that should be acknowledged. The first element that is worth to address, is the assumptions regarding the econometric method used for this research. Firstly, we demonstrated some non-linearities in our variables. This is something further research should address further. Secondly, time-series data is used, making the assumption about random sampling problematic. This is a weakness for the model presented, and further assumptions should be addressed to take on time-series data in a more complete way. As mentioned, the *no serial correlation* assumption for time-series data recognizes that the past affects the future. This assumption is not addressed in this thesis. A consequence of this can be that the estimation of the regression coefficients is inefficient. Further research should include and further address this assumption.

For a deeper understanding of the independent variables effect on the krone exchange rate, lagged variables could be interesting to include. Lagged independent variables would give the effect of previous values of the independent variable on the dependent variable. This would address that the exchange rate today may be affected by, for instance, the oil price of both today and previous periods. For further research, this may be interesting to add.

The model that is set up only include two control variables. Although the model has an adjusted R-squared of 68.7%, there should be emphasized that including a few additional variables could improve the precision of the analysis. Some variables that can be included in a further analysis is the current account deficit, the price differential between the two zones and maybe the S&P 500 index. A deficit in the current account normally leads to a depreciation of a country's currency, through decreasing demand (Holden, 2016, p. 353). Price differential could be interest in order to examine if inflation influence the exchange rate. Also, the S&P 500 index could be useful to include in the model. The purpose of this would then be to examine whether the prospect of a higher return in the US stock market leads investors to withdraw funds from a small currency, such as the Norwegian krone, and invest it in shares in the US (Naug, 2003). Including these variables could give a more detailed analysis.

There is also worth criticizing the data used in the *VIX*-variable. This variable was used to reflect increased turbulence and reduced willingness to take risks among the market participants. This thesis uses the highest registered value of the VIX-index for each month, however, the average value of this index should be used for further analyses, as it may provide a better indicator of the overall uncertainty in the markets. Changing this would maybe give some more accurate results.

To answer the question on "how much" the interest rate differential affects the krone exchange rate, we presented the standardized beta coefficients. These let us get insight on the relative impact of the explanatory variables, using a same unit of measurement. Although this set up our variable of interest, *IRDifferential*, against our control variables, it gives a limited answer on the actual relative impact of the interest rate differential. We can just say something about the impact of the interest rate differential relative to our other two explanatory variables. Many other variables should be included here to get a deeper insight on the relative effect. Also, the use of standardized beta coefficients is widely criticized. If we look at the equation for the standardized beta coefficients (*equation 6*), variables with large variance will be of more importance than variables with smaller variance. This itself, is not a good indication that a variable is of more importance. Furthermore, the comparison of standardized beta coefficients assumes that a change in one standard deviation entails the same change in all types of independent variables. We cannot simply assume that, for example, one standard deviation of the *IRDifferential* is the same as one standard deviation of the *OilPrice*. In addition, it is doubtful whether interpretation in standard deviations makes sense for variables that are very skewed (Johannessen, et al., 2020, p. 354). This makes the insight from our standardized beta coefficients questionable.

In total, these remarks emphasizes that the model's results contain several limitations. When drawing conclusions based on the results from this thesis, these limitations should be kept in mind.

5.2 Conclusion

This thesis presented an analysis of the interest rate differentials effect on the krone exchange rate. The objective of this study has been to determine how the politically controlled variable, interest rate, actually influence the krone exchange rate, and whether the Norwegian central bank can utilize the interest rate as a tool to maintain a stable exchange rate. According to the results of our estimated model, an increased interest rate differential indeed has a statistically significant effect on the exchange rate. To examine the relative effect from the interest rate differential, the standardized beta coefficients was presented. These suggested that the interest rate differential had the lowest impact of our three explanatory variables, around the same effect as the VIX-index. On basis of this analysis, it can be concluded that the interest rate differential has an impact on the exchange rate, but the effect can easily be overshadowed by other key factors affecting the exchange rate. The Norwegian central bank's ability to control the krone exchange rate through the interest rate level is hampered as a result of this.

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