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Oil price and the exchange rate

A study on how the oil price affects the Norwegian Krone exchange rate under different monetary policy regimes

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Preface

This thesis is a joint work between Tord Stokke Tryggestad and Jens Dahl Haagensen, concluding our 5 year master of science in economics at the Norwegian University of Science and Technology, NTNU. We would like to thank our supervisors Professor Ragnar Torvik and Professor Kåre Johansen for their inspiring and helpful feedback to our work.

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Summary and Conclusions

We show the existence of a statistically significant short-term relationship between the Norwegian exchange rate and the oil price, and how this effect increased following the introduction of inflation targeting by Norges bank. Assuming that both the theories of purchasing power parity and uncovered interest parity hold in the long run, we combine the two to form a theoretical equilibrium correction model. By assuming that the expected exchange rate is affected by some real factors, the oil price is included in the model. Emphasizing the role of monetary policy on the oil price effect we split our time period into two, before and after inflation targeting was officially introduced in Norway in 2001. Both ordinary least squares and Markov-switching estimations are performed on a dynamic log-linear model. The latter estimation method proves to be particularly well-performing with near perfect state predictions. As there is evidence of the oil price having asymmetrical effects, the same estimation procedures are performed allowing increasing and decreasing oil prices to have separate effects. We find that the oil price effect did, in fact, increase following the adoption of inflation targeting and that falling oil prices had more to say in this time period than increasing oil prices. In the managed float time period before 2001, the asymmetrical estimations indicate that only increasing oil prices was statistically significant. However, we find less evidence of asymmetrical effects in the this time period, suggesting more symmetrical and smaller oil price effects than under the more flexible inflation targeting monetary policy regime. Long-run solutions is found for all models, but do mostly not contain any statistically significant effects of the oil price or interest rates, implying that the equilibrium exchange rate is decided by the price difference between Norway and the EU. This is especially true in the post-2001 time period, suggesting stronger evidence of the equilibrium exchange rate being determined by purchasing power parity under inflation targeting than under the managed float monetary policy. In the pre-2001 time period, there are some statistically long-run oil price effects, but this could be due to the time-period being relatively short, suggesting that the oil price effects on the exchange rate are, in fact, short term. Although our speed of adjustment coefficient is somewhat low for a rapidly moving variable such as the exchange rate, our estimated half-life of such deviations are lower than those of the general consensus in the literature.

Contents

List of Figures

List of Tables

List of abbreviations

AR	Autoregressive
ADF	Augmented Dickey-Fuller
AIC	Akaike Information Criterion
ARCH	Autoregressive Conditional Heteroscedasticity
BLUE	Best Linear Unbiased Estimation
CA	Current Account
CPI	Consumer Price Index
DEM	Deutsche Mark
ECB	European Central Bank
ECM	Equilibrium Correction Model
ECU	European Currency Unit
EEA	European Economic Area
EU	European Union
GDP	Gross Domestic Product
GFC	Global Financial Crisis
GHI	Global Hazard Index
NIBOR	Norwegian Interbank Offered Rate
NOK	Norwegian Krone
NTNU	Norwegian University of Science and Technology
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
UIP	Uncovered Interest Parity
US	United States
PPP	Purchasing Power Parity
SBIC	Schwarz Bayesian Information Criterion
SSB	Statistisk Sentralbyrå
TOT	Terms Of Trade
USD	United States Dollar
VECM	Vector Error Correction Model
VAR	Vector Autoregression

1 Introduction

Following the start of the Norwegian "oil adventure" around the mid-1960's, oil and the industry around the production of it, have become a more and more vital part of the Norwegian Economy. Not only does the production and sales of oil generate revenues for "The Government Pension Fund Global", a fund for phasing oil revenues into the Norwegian economy, the sector employs a considerable proportion of the labour force and its performance has large repercussions throughout the rest of the Norwegian economy. According to Norwegian Petroleum (2017), export of crude oil and natural gas made up about 47% of Norway's total exports in 2016 and SSB (2017b) reports that the production made up an equivalent of around 21% of Norway's gross domestic product (GDP) in 2014. Although this sector's share of employment, export and total GDP have decreased over the last three years, the Norwegian economy is still heavily reliant on the oil price, and fluctuations in the oil price are believed to be responsible for several periods of appreciation and depreciation of the Norwegian Krone (NOK) exchange rate. This can be explained through that an increase in the oil price should raise demand for the currency of oil exporting economies. One can also argue that an increase in the oil price could create a wedge between the long-run equilibrium exchange rate and its actual level, resulting in an appreciation of the nominal exchange rate so as to correct the real exchange rate back toward its long-run value. Finally, if one is to assume that the long-run real exchange rate equals a constant, an increase in the oil price should give a correction of the real and nominal exchange rate back toward its equilibrium level through the purchasing power parity (PPP) theory. However, established as the theory may be, empirical studies have less convincing results on the effects of changes in the oil price on the exchange rate of oil exporting countries. This may be due to interventions of central banks, which may strive to maintain stability of the exchange rate. One should thus also include the monetary side of the economy when facing this issue, and this tells us that the choice of monetary policy in the economy may have significant effects on how the oil price affects the exchange rate.

We try to establish the relationship between the oil price and the exchange rate of the Norwegian Krone against the Euro by assuming that both the PPP and uncovered interest parity (UIP) conditions holds in the long run. Through the two, deviations from the long-run equilibrium exchange rate should cause corrections over time through an appreciation/depreciation pressure. This is also the base for several other research conducted on the issue, such as Akram (2002) and Bernhardsen and Røisland (2000). While the latter estimates a linear relationship in the period from 1993 to 2002, separating short and long term effects, the former establish a non-linear relationship in addition to a linear one, covering the period of 1972 to 1998. Akram (2002) investigates this non-linear relationship as both him and other previous authors find no or only weakly statistically significant effect of the oil price on the Krone exchange rate when using a log-linear model. He finds strong and statistically significant evidence of the oil price effect on the exchange rate when the oil price is below a threshold level and decreasing. On a slightly different train of thought, one can expect the oil price to have an increasing impact on the exchange rate with how freely floating the exchange rate is. If the exchange rate is pegged to another currency, the central bank of an oil exporting country may intervene to counteract the exchange rate effects caused by changes in the oil price, while it may not if the exchange rate is freely floating such as under an inflation targeting monetary policy. Authors such as Maruizio and Margarita (2007) investigate this role of the prevailing monetary policy regime in a country on the effects of the oil price on the exchange rate. However, they find no empirical evidence supporting this theory.

In addition to estimating the oil price effect on the exchange rate through both a linear and non-linear equilibrium correction model (ECM), we contribute to the research by investigating and focusing on the official change of monetary policy in Norway from a managed float to inflation targeting regime in the first quarter of 2001. We do this as there seems to be a clear rise in the volatility of the nominal exchange rate following this event. Our research also differs from previous work as we have access to more and up-to-date data, which we believe is sufficient to capture the effects of the change of monetary policy regime in Norway. This data also contains several shocks to the exchange rate which seem to have root in oil price movements, including the large fall in oil prices starting in 2014. By looking at our models prediction power of these events, we further contribute by trying to determine whether linear or non-linear estimations proves to fit the actual exchange rate movements better. These events have also made the issue of how much the oil price affects the NOK exchange rate a rather timely matter, and looking at whether or not this effect has increased following the introduction of inflation targeting relevant.

In order to investigate this issue, we look at whether or not the exchange rate effects following changes in the oil price has changed with the monetary policy regime. This is done by estimating both linear and non-linear ECMs for separate time periods using the ordinary least squares (OLS) estimation method. This separation is done in the first quarter of 2001, where we find clear evidence of a structural break following the introduction of inflation targeting. In addition, both models are estimated using a Markov-switching estimation method. The latter is a suitable method when facing regime changes, allowing for the effect of various variables to change with the monetary policy regime. In the linear model, we find strong and statistically sufficient evidence that the effects of changing oil prices did, in fact, rise following the adoption of inflation targeting. In addition to finding empirical evidence of the differing oil price effect, our Markov-switching estimation of the linear model has near-perfect predictions of the model belonging to the different monetary regimes at any point in time. In the non-linear model, we find that the impact of falling oil prices increased and became statistically significant after 2001, while increasing oil prices had a statistically significant effect only in the time period prior to 2001. We do, however, find less evidence of asymmetrical oil price effects in the latter time period, suggesting more symmetrical oil price effects. The Markov-switching estimations of this model further back up the OLS estimations conclusions, confirming our theories.

The rest of the thesis is structured as follows. In the next chapter, we summarise some of the previously written literature on the matter, before looking at the economic theory of exchange rate determination and our two equilibrating conditions in chapter 3. In chapter 4, we describe the data we use and its empirical properties, before the relevant empirical theory behind estimating our theoretical model is explained in chapter 5. In chapter 6, we describe the estimation and test results, and look at the estimations prediction power in some well-known events. Finally, we conclude on our findings and discuss possible extensions and shortcomings of our research in chapter 7.

2 Literature review

Of course, we are not the first that try to establish an empirical relationship between exchange rate movements and fluctuations in the oil price. Previous literature, however, concludes with mixed results, and Amano and van Norden (1998) focus on the persisting problem of econometric studies being unable to estimate good fitting models of exchange rate movements in the post-Bretton-Woods period. They argue that this research has mainly had three lines of development. The first one tries to find long-run relationships in monetary models of the exchange rate, the second one attempts on modelling of the purchasing power parity theory, while the third and one to focus on structural time-series, work on determinants of the real equilibrium exchange rate. The latter suggests that there exists some real factor causing permanent shifts in the real equilibrium exchange rate, i.e. there exists some macroeconomic variable(s) causing long-term movements in the real exchange rate. Although this theory is intuitively appealing, the empirical work has several gaps. As Amano and van Norden (1998) argue, the major movements in terms of trade (TOT) throughout this time span were driven by changes in the oil price. Based on this, they try to determine this real factor by examining the possibility of the real oil price causing permanent shifts in the real exchange rate, using the real oil price as a proxy for the terms of trade. Following the literature on time-series at the time of writing, they find what they believe to be a robust relationship between the real domestic oil price and the real effective exchange rate for Germany, Japan, and the United States. This paper, among others whom briefly will be presented in the next section, inspired a series of further work on the relationship between the oil price and exchange rate movements. Following this presentation, we include a discussion of our contribution to the research.

2.1 Previous empirical work

Chen and Chen (2007) argue that the results of Amano and van Norden (1998) can be explained as finding that the real oil price is the most important factor determining real exchange rates in the long run. In line with existing literature, Chen and Chen (2007) use panel data for a sample of G7 countries over a 33-year period in order to test whether or not exchange rates are cointegrated with the real oil price. Further, they examine the ability of the real oil price to forecast fluctuations in the exchange rates. They distinguish their research from existing literature by considering several measures of the oil price, as opposed to others whom only use one measure. They also use pooled data, introduce several tests to improve the robustness of the estimations, and most importantly, focus on a longer time span than others when modeling the effects of real factors such as the real oil price on the exchange rate. Using a theoretical framework similar to the one introduced in Obstfield and Rogoff (1996), a country is assumed to produce commodities in two sectors, tradable and non-tradable goods. This implies that one can assume the consumer price index to be a log-linear weighted measure of the prices of traded and non-traded goods. Further, one can look at an increase in the traded goods price relative to the non-traded goods price to see the effects on the exchange rate. If such an increase is greater for home than for foreign, home's terms of trade will worsen and depreciate home's real exchange rate. Through the PPP theory, this depreciation is corrected over time, depreciating the nominal exchange rate. Relating this to the oil price, we can look at a country which is relatively dependent on importing oil. An increase in the real oil price could increase the cost of tradable goods at home greater than that of foreign, causing a depreciation of home's real exchange rate which further leads to a depreciation of the nominal exchange rate. This is backed up by the empirical results of Chen and Chen (2007), which suggest that the real oil price may have been the dominant source of real exchange rate movements and that there is a cointegrating relationship between the two. This result holds for several measures of the oil price. Further, they find that real oil price has a significant forecasting power for real exchange rates, and their out-of-sample forecasting outperforms a random walk model.

Maruizio and Margarita (2007) also utilize a theoretical framework built on the Harrod-Balassa-Samuelson model from Obstfield and Rogoff (1996), where a positive shock to the terms of trade will increase wages in the exporting sector of an economy. Assuming wage equalization, this will further lead to an increase in wages and prices in the non-traded goods sector, appreciating the real exchange rate. As Maruizio and Margarita (2007) explains, this relationship has been empirically confirmed by several authors for non-energy exporting economies, suggesting strong evidence of a long-run relationship between the real exchange rate and real commodity prices. They contribute to the literature by testing this theory for the oil exporting countries Norway, Russia, and Saudi-Arabia, using the real oil price as a proxy for the terms of trade. This relies on the assumption that oil exports make up a large enough share of the oil exporting countries so that an increase/decrease in the oil price will make the terms of trade substantially better/worse. This assumption is further backed up by Baxter and Kouparitsas (2000), which find that most of the terms of trade fluctuations of oil producing economies come from what they call a "goods price effect", reflecting the fact that countries export and import different goods. (Maruizio and Margarita, 2007, p.8).

Further, they chose these three countries as there already existed a vast literature researching and establishing a clear relationship between the oil price and real exchange rate in oil exporting countries such as Algeria and Venezuela. Concerning Norway, however, there have been mostly mixed results of the effects of oil price fluctuations. As for Russia and Saudi-Arabia, there have been few studies investigating their relationship. These three were also chosen as they all have adopted different exchange rate regimes in the time period under investigation. However, they only find the existence of a long-run robust relationship between the real exchange rate and the real oil price in the Russian case. They find no common stochastic trend between the two in the case of Saudi-Arabia, and concerning Norway, they find only a marginal effect. Regarding the effects of different exchange rate regimes, they find the rather surprising result that the Norwegian nominal exchange rate is the most stable of the three when subject to a shock in the oil price, even though Norway is the one that should have the most freely floating exchange rate according to its monetary policy regime of the time period. In the Russian case it seems that oil shocks have been caught up in the real exchange rate, i.e. the real exchange has appreciated in line with increments of the real oil price. Summing up, they find no evidence in favor of the different exchange rate regimes playing a significant role in determining the effect of the real oil price on the real exchange rates. They conclude that other factors such as monetary policies sterilizing volatile oil prices, and thus oil revenues, are key to understanding the relationship between the real oil price and the real exchange rate

Akram (2002) chooses to take a slightly different approach to solve the puzzle of the weak relationship between the Norwegian Krone exchange rate and the oil price. He argues that the results of earlier studies could be caused by them using log-linear models, implying that increases and decreases in the oil price have symmetric effects on the exchange rate. Akram (2002) therefore investigates whether or not there is a non-linear relationship between the two, as he argues that the linear assumptions made in previous studies might be too simplistic to capture the real relationship. This can be explained by the intervening behaviour of a central bank with the goal of stabilizing exchange rate fluctuations through adjustments of the interest rate. One can argue that these interventions will only occur when the shocks lie within a given range, i.e. the shocks are not too large. If the economic shock is of great significance, i.e. outside the given range, the central bank may abandon its stabilising policy due to the required change in the interest rate being of such a size that it may destabilise the economy. This could mean that the economy would benefit more from allowing fluctuations in the exchange rate rather than keeping it stable. Thus, the Norwegian central bank may use the interest rate as an instrument to stabilise the Krone exchange rate for relatively small fluctuations in the oil price, while abandoning its goal of stabilizing the exchange rate for relatively large shocks in the oil price. Using an ECM on the trade-weighted Norwegian exchange rate against a set of variables, he estimates both a linear and non-linear model. The linear model replicates the results of previous studies, with evidence of no statistically significant relationship between the exchange rate and the oil price. The non-linear model, on the other hand, gives strong evidence in favor of a negative relationship, especially when the oil price is below a threshold value and falling. Akram (2002) then adds further credibility to the non-linear model by testing its robustness and through out of sample modeling which clearly favors the non-linear model over both the linear and a random walk model.

In Bernhardsen and Røisland (2000), the authors try to pinpoint which factors that affect the

Norwegian Krone exchange rate and its deviation from the purchasing power parity hypothesis. Empirical evidence speaks in favor of the hypothesis being non-applicable in the short run, while several studies find evidence of it holding in the long run. If the price level in a country rises more swiftly than in other countries, there is a tendency for its currency to depreciate correspondingly over time. Utilizing the theory of terms of trade and the exchange rate determination developed in Obstfield and Rogoff (1996), they argue for a strengthening of the Norwegian Krone exchange rate due to an increase in the oil price. However, they argue that the role of the Norwegian government petroleum fund can influence the degree of dependence of the domestic economy on the oil price. If the economy is relatively little dependant of petroleum revenues (the fund), it will be less prone to fluctuations in the oil price.

Bernhardsen and Røisland (2000) differ from Akram (2002) in the sense that they include the Global Hazard Indicator (GHI), a measure of international financial instability. They do this in order to capture a tendency for international investors to reduce their holdings in the Norwegian Krone in times with increased international financial instability, making the Krone a "peripheral" currency (Bernhardsen and Røisland, 2000, p.2). This could be a possible explanation to why the Norwegian Krone exchange rate in the 90's experienced a tendency to depreciation despite rising oil prices. To account for uncovered interest parity, they include interest rate differentials, but take the estimation results from this variable with caution. Central banks have historically raised their key interest rates as their currency experiences depreciation pressure, which may cause it to be an endogenous variable. Using a linear ECM, Bernhardsen and Røisland (2000) find both, at least weakly, statistically significant negative short- and long-term oil price effects on the NOK/DEM exchange rate. They also find statistically significant effects of the financial instability and interest rate differential in the short-run, but not in the long-run. Estimating an ECM using the trade-weighted Krone exchange rate, they find a long term appreciation from increased oil price, coinciding with their previous results. For both exchange rate measures, they find a high degree of mirroring in the movements of the actual exchange rate and their estimated equilibrium exchange rate, and a clear pattern of the Norwegian exchange rate depending on the price differential between Norway and other countries.

Bjørnland and Hungnes (2005) look at the link between the long-run PPP and the current account in order to see the effect of TOT-altering price changes, as they argue that the cause of long-run deviation from PPP comes from massive capital movements. They apply the this theory on data for the Norwegian Krone exchange rate, and include the oil price due to oil being the main export commodity of Norway. They find that PPP does not hold in the long run and that when interest rate differentials between Norway and its trading partners are included, the real oil price only play a minor role in determining the long-run real exchange rate.

Basnes et al. (2014) study the relationship between the Norwegian Krone and the Canadian Dollar against the US Dollar to find how the real exchange rate is affected by changes in the brent barrel oil price. They do this in order to find common cycles and trends in exchange rate movements of the currencies. This is motivated by what they think to be a wrongful focus in the existing literature on the subject on finding a stochastic positive or negative relationship between the two variables. Instead of doing this, Basnes et al. (2014) focus on finding whether there is a common dynamic of the currency movement of oil exporting countries. Their results indicates a strong correlation between the exchange rates and the oil price, and between the two exchange rates themselves. The latter could indicate that there exist some common factor the two are linked to. As the international oil market is predominantly traded in US Dollar, they suggest that this link may be the movement of the US Dollar, i.e. a higher oil price is accompanied by an appreciation of the Canadian Dollar and the Norwegian Krone, depreciating the US Dollar against the two.

There have also been several studies explicitly taking into account the fact that oil is primarily traded in US Dollars. Zhang et al. (2008) look at the relationship between the fluctuations of the US dollar exchange rate and the oil price. International crude oil trading is primarily done in US Dollar, implying that movements in the US exchange rate may underlie the volatility of the crude oil price. This would mean that crude oil importing countries other than the US itself, could be affected by a change in and the volatility of the US dollar.

Although all of these authors have tried to find an answer to the question of how oil prices affect the exchange rate for oil exporting economies, there are still unanswered questions on this issue. Maruizio and Margarita (2007) focus on the effect of different monetary policies, but utilize panel data in their approach. This could lead to country-specific differences between their selected countries affecting the results. Akram (2002) and Bernhardsen and Røisland (2000), on the other hand, both utilize data on the Norwegian exchange rate for the time period prior to the introduction of inflation targeting. Although inspired by all of the above, we contribute to the research by combining ideas especially from these three articles in trying to solve our main issue: How much does the oil price influence the Norwegian exchange rate against its main trading partners, and has this influence changed with the adoption of a new monetary policy regime? We use a longer time span than the previous authors and are, at least to our knowledge, the first to look at how the relationship changed following Norway's adoption of inflation targeting as a monetary policy. We also contribute by comparing the prediction power of both linear and non-linear models in some well-known events where the oil price rose or fell sharply.

In order to do this, we must, like several of the above authors, assume a long term equilibrium exchange rate to hold based on some economic theory. Which ones and the theory behind is explained in the following chapter.

3 Economic theories of exchange rate determination

A modern open economy heavily reliant on global trade is, in many ways, dependent on the exchange rate of its currency against other currencies. From the real value a company receives from selling a commodity abroad to the price a citizen have to pay to fill up his car with petrol, it all depends, at least to some degree, on the exchange rate. This means that the general state of the economy evolves and varies with the exchange rate against its trading partners currencies. As Norway is a relatively small and a very open economy, the Krone exchange rate against the currencies of Norway's trading partners has a great importance to the development of the Norwegian economy. Further, as the main exporting commodity of Norway is oil, it is reasonable to think that the Norwegian exchange rate depends on, and varies with the often sharp fluctuations of the oil price. In the following chapter, we will establish a theoretical framework for international trade, exchange rate movements and how oil prices may affect it.

3.1 Intertemporal trade and the current account

A perk of being a part of the international economy is that a country can use trade as a mean to allocate resources over time, borrowing or lending resources as needed. This resource exchange over time is called intertemporal trade. In our context, this gives a country the opportunity to borrow in order to counteract a downfall in consumption or investments following a fall in the oil price, and invest in overseas projects to gain revenue when the oil price is high. Such a surplus or deficit is measured by the current account balance, which is defined as the change in a country's net claims to the rest of the world over time, the change in its net foreign assets. This means that if a country is borrowing over time it experiences a current account deficit, and a current account surplus if it is lending to the rest of the world.

An alternative to the direct lending of assets to overseas countries is through exports. If a country is a net exporter of goods and services to other countries, it will generate a current account surplus and vice versa. A net exporter acquires foreign assets through payments for its goods and services. This balance of payments is recorded as a country's net sales of assets to foreigners under its capital account balance, equating a negative of the current account items, i.e. every positive item of net export is equated by a negative capital account item, an acquirement of the foreign asset by a payment from abroad. From an accounting point of view, this means that the net export and capital account always has a net sum of zero. We do, however, only focus on the current account as it is a measure over time, showing the change in a country's net foreign asset from one time period to the next. The country's net export, on the other hand, focus on factors determining movements within each time period.

The current account balance is thus an important building block of any economic theory of international trade as it indicates whether or not and to which degree an economy is borrowing or lending from its trading partners. However, we have ignored the role of prices in international trade until now. This is, however, a clear simplification, and the inclusion of prices will be discussed in the following section.

3.2 Real exchange rate, Purchasing Power Parity and Terms of Trade

Prices on the goods an economy exports and imports play a crucial role in international trade. In order to take this into account, the normal procedure is to use an aggregate price on groups of commodities to find the ratio of national price levels to foreign price levels. This gives the real exchange rate of an economy, ε, which Obstfield and Rogoff (1996) defines as the relative cost of the common reference basket in the two economies compared in a common numeraire. This can be expressed as $\varepsilon = \frac{EP^*}{P}$, domestic prices compared to foreign prices, or alternatively in its natural log form as $\epsilon = e + p^* - p$. Home experiences a real appreciation of its currency if $\frac{P}{P^*}$

increases, implying that foreign experiences a real depreciation of its currency against home's currency.

This brings us further to the theory of purchasing power parity. One version of this theory, the absolute PPP, can be expressed by $P_t = E_t P_t^*$ and states that the real exchange rate should equal unity, or have the tendency to quickly return to unity after a disturbance to its long-run ratio. This builds on the assumption of the law of one price, which states that a commodity should, in absence of barriers to trade, sell for the same price everywhere. If this was not true, the concept of arbitrage would ensure a correction back to unity, i.e. the market would correct itself in a perfect trade world. This is, at least in the short run, not always very realistic as most countries have trade barriers of some sorts, and there are other factors such as transport costs affecting price level differences of commodities across the world. One can thus argue that PPP is a long-term relationship due to goods arbitrage happening slowly. A weaker version of PPP, the relative PPP, can be expressed by stating that changes in the national price levels are equal to or tends to equal unity, given a sufficiently long enough time to correct itself after a disturbance. If PPP holds in the long run, this means that the real, and thus the nominal, exchange rate should have a long-run equilibrium level equal to some constant, $\frac{EP^*}{P} = A$, or expressed in natural logarithm, $e + p^* - p = a$. If we, however, assume that we are not in the equilibrium state, but rather that there is a deviation from PPP, we can argue that the nominal exchange rate will drift towards its equilibrium level over time, which can be expressed as

$$\Delta e_t = -\alpha(e + p^* - p)_{t-1} + \sum_{j=0}^{p} \beta_j \Delta X_{t-j} + a \tag{3.1}$$

Here $0 < \alpha < 1$, and ΔX_{t-j} is a vector of lagged values of the terms included in the PPP relationship with a vector of corresponding coefficients, β_j. An increase in the real exchange rate would mean that the nominal exchange rate is above its equilibrium level, causing a downwards correction of the nominal exchange rate back towards its equilibrium level. It is reasonable to assume this as empirical results do not bode well for the PPP theory holding at every point in time, but rather suggest this kind of correction is caused by deviations from the long-term equilibrium. However, the PPP theory may not be sufficient in order to explain movements in the exchange rate by itself, as it ignores interest rate effects. We thus introduce another correcting relationship in order to explain the exchange rate movements.

3.3 Uncovered interest parity

The uncovered interest parity is an important building block of any monetary model and holds through the market correcting for arbitrage. Following Obstfield and Rogoff (1996), we let i_{t+1} be the interest rate on bonds denominated in home's currency at time period t, and similarly i^*_{t+1} for foreign bonds. UIP will then hold as long as the following is true.

$$(1+i_{t+1}) = (1+i^*_{t+1})\varepsilon_t\left(\frac{E_{t+1}}{E_t}\right)$$

This states that any investor can at any point in time buy foreign bonds for one unit of domestic currency equal to $\frac{1}{\varepsilon_t}$, and receive $1+i^*_{t+1}$ in principal payments and interest rates. This can then be converted back to the domestic currency at date $t+1$, and the investor should receive the same payoff as he would have received by investing in domestic bonds, $1+i_{t+1}$. In other words, the investor would receive the same payoff by investing abroad as he would by investing at home. This does, however, rely on the assumption of perfect foresight. In the real world, this does not hold, and factors such as exchange rate risk may drive a wedge in the UIP relationship. This wedge is in many monetary models treated as a constant, and the UIP theory works together with the theory of PPP in monetary models. These models are often somewhat weak in the short-run but useful in estimating long-run relationships, providing the intuition that the exchange rate should be viewed as an asset, which like other assets are reliant on the expectations of future variables. Assuming the expected exchange rate equals the exchange rate in the next period and rewriting the UiP condition, we can express the nominal exchange rate as $E = \frac{1+i^*}{1+i}E^e$, or in natural log as $e = ln(1+i^*) - ln(1+i) + e^e \approx i^* - i + e^e$. If we assume that UIP holds in the long run, the real equilibrium exchange rate will equal some constant, c, such that $e - (i^* - i + e^e) \approx c$. As with the long-run PPP condition, we can express a state of deviation from

UIP in the following sense

$$\Delta e_t = -\Pi(e - (i^* - i) + e^e)_{t-1} + \sum_{j=0}^{p} \beta_j \Delta Z_{t-j} + c \tag{3.2}$$

Also here, we have $0 < \Pi < 1$ and ΔZ_{t-j} as a vector of terms at lag j with β_j as a vector of corresponding coefficients. A deviation from the UIP condition over the long-run equilibrium will result in a negative correction of the exchange rate back towards the equilibrium level.

However, e^e is partially unobservable in real world applications, and we thus need to include something in our model to explain movements in the expected nominal exchange rate. One alternative could have been to use the forward exchange rates, but these are mostly based on interest rates and we could face an endogeneity problem. In addition, the empirical evidence of the forward exchange rates actually predicting the future spot exchange rates is mixed.[1] We thus choose to include a range of variables we believe will reflect the market's expectations of the future exchange rate. Which ones and the reasoning is discussed in the following section.

3.3.1 Factors affecting the expected exchange rate

In theory, the connection between the oil price and the exchange rate of oil exporting economies is well established by a vast selection of theories. One can expect that increased oil prices will lead to an appreciation of the economies exchange rate, and vice versa. One framework explaining this movement is the theory of exchange rate determination developed in Obstfield and Rogoff (1996), which utilize the mechanics of the terms of trade on the exchange rate through the Harrod-Balassa-Samuelson effect. In short, this effect is the tendency for countries with high productivity in their traded goods sector relative to their non-traded goods sector to have a higher price level overall. In addition, non-traded goods are less prone to standardization and mechanization than traded goods as non-traded production tends to be more labour-intensive. Thus, there is a historical tendency of the productivity growth in the non-tradable sector to be lower than that of the tradeable sector (Obstfield and Rogoff, 1996, p.209). Combining the two, we should expect high export based economies to have a high productivity, and thus a high

[1] See for example Agmon and Amihud (1981) or Vij (2002).

price level in their traded goods sector. Rich countries should have become rich through high productivity in their traded goods sector, and price levels tend to rise the per capita income.

Assuming the world consists of countries with two sectors, traded and non-traded goods, and a uniform price for a basket of traded goods, the real exchange rate can be represented as the relative price of traded goods, P_T, to the price of non-traded goods, P_{NT}. Further, this equals the nominal exchange rate times TOT, such that $\epsilon = \frac{EP^*}{P} = \frac{P_T}{P_{NT}}$.[2] An increase in the economy's export prices relative to its import prices implies a real appreciation of the economy's currency against its trading partners, i.e. we have a positive relationship between the terms of trade and the real exchange rate of an economy. Increased demand for the economy's exports increases export revenues, further appreciating the nominal exchange rate. In terms of oil exporting countries such as Norway, an increase in the oil price relative to the price of the commodities that Norway imports, will lead to a real appreciation of the Norwegian Krone. Assuming we initially have the long-run equilibrium exchange rate, we should see a negative correction of the exchange rate toward its equilibrium level following an increase in the oil price. This, however, relies on the assumption that the oil share of Norway's export is of great significance. We can safely assume this, as according to SSB (2017a), oil export accounted for about 40% of Norway's total exports from 1990 up til around 2010. Although falling down towards 25% from 2010 to 2016, this is still quite high, and we conclude that an increase in the oil price should cause an appreciation of the Norwegian Krone exchange rate while a decrease should cause a depreciation.

As the exchange rate is the price foreign investors have to pay in a foreign currency in order to acquire one unit of the Norwegian currency unit, the exchange rate depends on the supply and demand of NOK. Foreigners need Norwegian currency in order to pay for their imports from Norway, and vice versa. This means that whether or not, and to which degree, the economy is borrowing or lending to its trading partners, may affect the expected exchange rate. We thus include a measure of the current account balance relative to the GDP in our relationship. We also include the Norwegian interbank offered rate (NIBOR) in order to capture the effect of the domestic money market interest rate on the exchange rate. A higher interest rate should mean

[2] Although we chose to use this representation of the real exchange rate, the are also other possible representations such as a weighting of foreign prices to non-traded prices $\epsilon = \frac{EP*}{(EP*)^{\alpha} P_{NT} 1-\alpha} = \frac{(EP*)^{1-\alpha}}{P_{NT}^{1-\alpha}} = \left(\frac{EP*}{P_{NT}}\right)^{1-\alpha}$.

more foreign investors would want to invest in Norway in order to receive higher returns on their investments, increasing demand for the Norwegian currency and causing an appreciation of the exchange rate.

Using these variables for explaining the expected exchange rate allows us to modify the UiP condition by removing e^e. To catch up the effect of changes in the oil price on the nominal exchange rate and its expected value, we include a function f which contains lagged oil price and the lagged first difference values of it. NIBOR and the relative current account deficit to GDP are included in ΔZ_{t-j}.

$$\Delta e_t = -\Pi(e-(i^*-i))_{t-1} + \sum_{j=0}^{p} \beta_j \Delta Z_{t-j} + f_t\Big(oilp_{t-1}, \sum_{j=0}^{p} \Delta oilp_{t-j}\Big) + c \tag{3.3}$$

3.4 Combining PPP and UiP

As seen, we can explain deviations from and correction towards the long term level of the exchange rate through both the UiP and PPP theories. In theory, the two are supposed to hold simultaneously, and we combine the two relationships (3.1) and (3.3), assuming that Πe_{t-1} is caught up in the real exchange rate through αe_{t-1}. The latter means we can extract the nominal exchange rate from the UIP condition, making the relationship explaining the equilibrating movements in the exchange rate more flexible.

$$\begin{aligned}\Delta e_t = &-\alpha\big(e+p^*-p\big)_{t-1} - \Pi\big((i-i^*)\big)_{t-1} + \sum_{j=0}^{p}\Big(\delta_j \Delta e_{t-1-j} + \beta_{1j}\Delta p_{t-j} + \beta_{2j}\Delta p^*_{t-j} + \beta_{3j}\Delta i_{t-j} + \beta_{4j}\Delta i^*_{t-j} \\ &+ \beta_{5j}\Delta\Big(\frac{CA}{GDP}\Big)_{t-j} + \beta_{6j}\Delta NIBOR_{t-j}\Big) + f_t\Big(oilp_{t-1}, \sum_{j=0}^{p}\Delta oilp_{t-j}\Big) + c\end{aligned} \tag{3.4}$$

In the following chapter, we introduce the data we use in order to estimate this relationship and which considerations we need to take into account concerning the data's properties.

4 Data description and empirical properties

In this chapter, we describe the data and its properties for the variables we will use in estimating the theoretical relationship from chapter 3. We begin with a formal description of the data with motivation for its inclusion, its expected effect on the exchange rate and where the data was found. We then look at the data visually and discuss why this might be useful before we introduce and test for stationarity in the data.

4.1 Data description

Based on the theoretical relationship between the Norwegian exchange rate and the oil price, we include the following set of variables. Variables denoted $i = f$ indicates data for the EU, and Norwegian data else. All our data is either originally or modified to quarterly data and pulled from different publicly available databases. Our time frame is from the first quarter of the year 1990 up to and including the third quarter of 2016.

variable	explanation
E	NOK-ECU nominal exchange rate.
OILP	Average quarter price Crude Brent oil price in USD.
RBi	5-yearbond interest rates issued by the Norwegian government and the ECB.
NIBOR	3 month Norwegian Interbank Offered Rate.
$CPIi$	Consumer price index, year 2010=100.
FYI	Current Account balance relative to GDP.

4.1.1 NOK-ECU exchange rate

In order to find the effects of the oil price on the Norwegian Krone exchange rate, we chose to use the exchange rate between NOK and the European currency unit (ECU). This is done as, according to SSB (2017a), export to countries within the European Union (EU) accounts for around eighty percentage of the Norwegian export, making the EU Norway's largest trading partner. In addition to geographical advantages, this is due to Norway belonging to the European Economic Area (EEA), giving tax-free import and export for a series of products between Norway and the other members of the EEA. In addition, Norway is the second largest exporter of oil and gas to the EU, making the NOK-ECU exchange rate a good measurement of the Norwegian Krone when looking at the effects of the oil price. We also chose the NOK-ECU exchange rate as we could have faced an endogeneity problem by choosing the NOK-USD exchange rate instead. Oil prices are usually measured in USD, and an increase in the oil price could have two contradicting effects on the exchange rate.

Our exchange rate measure is NOK per ECU such that an increase in the exchange rate value means that you need to pay more NOK per ECU, i.e. the exchange rate depreciates. On the contrary, a decrease in the exchange rate value means that the Krone becomes relatively more valuable, and the exchange rate appreciates. As we are partially looking at the time before the Euro was introduced as the official currency unit of the EU, we use both the ECU and the Euro as a currency unit. The ECU was calculated as a weighted average of the currency units of 12-15 of the member states of the EU and replaced by the Euro on January 1, 1999, at parity. We thus use the NOK-ECU exchange rate from 1990 til 1999, and the NOK-EUR exchange rate for the rest of our time period. The data on the NOK-ECU exchange rate is pulled from Eurostat, while the NOK-EUR exchange rate data is provided by Norges Bank, the central bank of Norway.[1,2]

[1] http://ec.europa.eu/eurostat
[2] http://www.norges-bank.no/Statistikk/Valutakurser/

4.1.2 Oil price

Through the Harrod-Balassa-Samuelson effect explained earlier, we established an economic theory of how changes in the oil price are expected to affect the oil price. According to our theoretical framework, an increase in the oil price is expected to appreciate the Norwegian Krone exchange rate, i.e. the coefficient of the oil price variable is expected to be negative. To include the oil price, we have used the price of European brent crude oil, denoted in US dollars. The latter comes from oil primarily being traded in US dollars. In addition, using an oil price denoted in Euros could mean that changes in oil price would have double effects on the exchange rate. Increased oil prices would imply an appreciation of the NOK-ECU exchange rate, increasing NOK earnings from Norwegian oil export. At the same time, the number of Euros Norwegian oil exporters can sell their oil for is reduced in NOK value, implying two contradicting effects of increased oil prices. By using an oil price denoted in US dollars we can isolate the effects of changes in the oil price on the exchange rate. The oil price data is gathered from the U.S Energy Information Administration.[3]

4.1.3 Consumer price indexes

In order to control for the effect of differences in the inflation in Norway and the EU, we include both their consumer price indexes (CPI). Inflation is connected to the nominal exchange rate through the real exchange rate. An increase in the domestic inflation relative to the inflation abroad should reduce foreign demand for Norwegian goods, depreciating the nominal exchange rate, i.e. the value of the nominal exchange rate is increased. Both CPI are indexed with year 2010=100, and pulled from the OECD.[4] Due to data availability and in order to keep consistency, we use EA19 data for the EU CPI. The same data is also used with the exchange rate to create our measurement of possible long term deviation from the equilibrium level of the nominal exchange rate under the PPP hypothesis.

[3]https://www.eia.gov/
[4]https://data.oecd.org/

4.1.4 Interest rates

Seeing as differences in the bond interest rates between Norway and the EU could affect the demand for the two currencies and thus the exchange rate, we include the 5-year bond interest rates from both Norges Bank and the European Central Bank (ECB). A higher interest rate in Norway compared to its trading partners makes it more desirable to invest in Norwegian bonds. This increases demand for the Krone, making it relatively more valuable. This implies that the Norwegian Krone exchange rate should appreciate, decreasing in number value. The data for the Norwegian bonds is provided by Norges bank, while the European bonds are provided by the ECB.[5,6]

In order to include the effect of the domestic money market may have on the exchange rate, we include the Norwegian interbank offered rate, which is a 3-month money market interest rate. An increase in the money market interest rate should give similar effects as a relative increase in the bond rate, appreciating the nominal exchange rate. The NIBOR data is provided partially by Norges bank and partially by the Oslo stock exchange.[7,8]

4.1.5 Current account and gross domestic product

To capture the effect on the exchange rate of whether or not, and how much, Norway is borrowing or lending to the rest of the world, we include the measure FYI as Akram (2002) did. This variable equals the current account balance relative to the country's gross domestic product, giving us an idea of the relative size of a country's trade balance. The theoretical relationship between the two can be explained by looking at a depreciation of the Krone exchange rate. This makes Norwegian goods relatively cheaper for our trading partners, increasing the competitiveness of Norwegian exporting firms. Although the effect depends on the elasticity of demand and how firms change their pricing on the foreign currency, demand for Norwegian goods should

[5] http://www.norges-bank.no/Statistikk/Rentestatistikk/

[6] https://www.ecb.europa.eu/home/html/index.en.html

[7] http://www.norges-bank.no/en/Statistics/Historical-monetary-statistics/Short-term-interest-rates/

[8] https://www.oslobors.no/

increase. At the same time, Norwegian imports should decrease as foreign goods become more expensive. This means that Norwegian exports increase while imports decrease, generating a current account surplus. We should thus expect the coefficient of FYI to be positive, as the theory states a positive relationship between FYI and a depreciation of the exchange rate. To create this variable, we use data for the Norwegian current account balance and the GDP, both provided by the statistics bank of Statistics Norway.[9]

4.2 Data properties

As we use time-series data we have to take into account some specific econometric challenges, and some data transformations may be needed in order for estimations to be empirically solid. A good starting point for any time series analysis is to look at the data's specific time series characteristics. After plotting the variables over time and looking for such characteristics, more formal tests are applied. These inspections and test results are described in the following sections.

4.2.1 Visual inspection

Following the normal procedure of time series analysis, we start with visual inspections of our variables. By doing this, we can get an idea of whether or not the time series data seem to follow a seasonal pattern, trend or moves around a non-negative value, i.e to include a constant or not. A seasonal pattern means that the data follows a pattern corresponding to specific time periods. A good example of this is weather data, which often changes with the season of the year. If one fails to take seasonality into account when the data contains such seasonal trends, the result will, as Lütkepohl and Krätzig (2004) explains, most likely be a misspecified model with autocorrelation of the residuals in the same order as the seasonality. If the data seem to be evolving with a negative or positive trend line, this will have to be taken into account when performing the various tests. The ultimate point of performing these checks and correct according to their outcome is to be able to isolate the stochastic trends in the time series data from non-stochastic

[9] https://www.ssb.no/statistikkbanken/

variations. Failure to do this when needed could make our tests on the data properties worse off, and could, in the worst case, make our estimations questionable at best.

Looking at the time-plot of the nominal NOK-ECU exchange rate and the oil price in figure 4.1, there are several moments worth noting. In the early years of the 1990's, we see that the exchange rate is very stable although there are movements in the oil price. This is due to the Krone being fixed to the ECU throughout this time period. Following this, we see coinciding movements of the two variables, especially up against the turn of the century. As mentioned, the Norwegian central bank introduced the inflation targeting regime in 2001, and there are clear signs of a structural break following this event, increasing the volatility of the exchange rate quite drastically. This can be seen from the time-plot of the changes in the nominal exchange rate in figure 4.1, which becomes larger and more frequent up to and following 2001. In addition to generally rising, the oil price also has larger movements following the turn of the century, and the two variables now seem to mirror each other's movements to a higher degree than before. We also recognize some well-known events, such as the oil price increase and fall following the Iraqi invasion of Kuwait in 1990, the fall in oil price during the global financial crisis (GFC) and the more recent 2014 sharp decrease in oil price. The last two of these events are clearly visible in the exchange rate, but we also see large fluctuations in the exchange rate seemingly independent of large oil price movements, such as during the speculative attacks on the Krone exchange rate during the late 90's and following the adoption of inflation targeting.

Figure 4.1: Oil price and nominal exchange rate (left) and changes i the nominal exchange rate (right)

In addition to causing a structural break in the nominal exchange rate, the change of monetary policy also seem to cause a structural break in the real exchange rate, $e + cpif - cpi$, as it contains the nominal exchange rate. This structural break will be a vital part of our analysis, and testing for it with more formal empiric tests are in order. We do this by performing simple post-estimation supremum Wald tests for a structural break on a simple OLS regression of our variables. Although not reported, the test results clearly speak in favor of a structural break in the data.[10] Further, we test for the structural break happening at specific points of time, which give clear indications of the structural break happening at or around the first quarter of 2001. Due to this, we proceed the rest of our research by looking at the periods separated in addition to as a whole. The rest of the time series plots of our data can be seen in the graph section of the appendix. Looking at these, however, we find no clear evidence of seasonality or trends in our data, except for trends in the quite obvious case of the consumer price indexes.

4.2.2 Stationarity

When dealing with time series, stationarity may be a desirable property for any autoregressive (AR) stochastic process. This is briefly explained by Brooks (2008) as a model where the current value of a variable depends on its previous values and an error term, $y_t = \mu + \sum_{i=1}^{p} \alpha_i y_{t-i} + u_t$. Non-stationarity of this process will make the previous value of variables permanently affect their present value, i.e. y_{t-i} would have declining effects over time on y_t in a stationary process. In order for the process to be stationary, it has to have time-invariant first and second moments, which, as Lütkepohl and Krätzig (2004) explains, holds true in a simple case if

$$E(y_t) = \mu_y \quad \forall \quad t \in T$$

$$E[(y_t - \mu_y)(y_{t-h} - \mu_y)] = \gamma_h \quad \forall \quad t \in T \text{ and all integers } h \text{ such that } t - h \in T$$

The first condition gives that the stochastic process fluctuates around a constant mean and do not contain trends of any kind, while the second condition gives that the variance is time in-

[10] The OLS was performed on E against all explanatory variables in level form, and the null hypothesis of no structural break was rejected at a 0% level of significance

variant. In order to make the data closer to a stationary process, a simple log transformation can be performed. This may reduce the relative size of large fluctuations and help to stabilize its variance, making the series more in line with a normally distributed process (Lütkepohl and Krätzig, 2004, p.19). Other transformations include pulling out seasonal patterns or trends if present. The first can be done by filtering and the latter by taking the first difference of each variable. If a process becomes stationary after taking the first difference of it, we can say that the stochastic process is integrated of order one, I(1), while it is integrated of order I(0) if it's initially stationary. In general, we say that a stochastic process, y_t, is integrated of order I(d) if $\Delta^d y_t$ is stationary, but $\Delta^{d-1} y_t$ is not.

4.2.3 AR order specification criteria

Before performing estimations or various test, we have to perform some kind of model specification and selection, especially concerning the optimal lag length of each AR(p) process. This is done by applying some AR order selection criteria performing tests for model adequacy and model reduction. Two of these selection criteria frequently used are the Akaike Information criterion (AIC) and the Schwarz criterion (SBIC). AIC has the property of asymptotically overestimating the order with positive probability and SBIC being strongly consistent and more parsimonious (Lütkepohl and Krätzig, 2004, p.34). The model selection is then done by choosing the AR(p) order which, for all number of lags interesting, gives the lowest value of the chosen information criterion. The optimal lag length for each of our AR(p) used to test for stationarity can be seen in table B.1 in the appendix, where also the test results are found. The latter will be explained in the following section.

4.2.4 Unit Root Test

One test on whether or not our stochastic process is stationary is the augmented Dickey-Fuller (ADF) test. This checks a null hypothesis of the AR(p) process containing a unit root against the alternative hypothesis of it being stationary. The test can be specified to include a nonzero mean, deterministic linear trend or seasonal dummy variables. Looking again at a standard

AR(P) process such as $y_t = \mu + \sum_{i=1}^{p} \alpha_i y_{t-i} + u_t$, the process will be integrated if $\alpha(1) = 1 - \alpha_1 - ... - \alpha_p = 0$, and we thus want to test whether or not $\alpha(1) = 0$ or not. This is done by testing the null hypothesis $H_0 : \phi = 0$ against the alternative $H_A : \phi < 0$ in the following relationship.

$$\Delta y_t = \phi y_{t-1} + \sum_{j=1}^{p-1} \alpha_j^* \Delta y_{t-j} + \mu + u_t \tag{4.1}$$

Which is obtained by subtracting y_{t-1} from the AR(p) process. Further we have $\phi = -\alpha(1)$ and $\alpha_j^* = -(\alpha_{j+1} + ... + \alpha_p)$. The number of lags included in the test is based upon the previous order of the lag selection criterion chosen. The test thus shows us whether or not the process is stationary at the selected AR(p) order. Failure to reject the null hypothesis means we have a non-stationary process, and a first difference transformation is needed in order to make it stationary. Further, a rejection of the null hypothesis on an ADF-test on the first differentiated terms means the data process is integrated of order I(1), while failure to reject the null indicates that the process is integrated of an order greater than one. If the latter is the case, taking the first difference more than once is needed in order to make the process stationary. The test results from the ADF tests can be seen in table B.1 in the appendix, and suggest that that e and $e+cpif-cpi$ are integrated of order I(0), i.e they do not contain a unit root, while the other variables are integrated of order I(1). This is, however, the case of testing for a unit root over the whole time period, while, according to Brooks (2008), it is well known that unit root tests have low power when subject to a structural break. The ADF test does not always manage to separate between a process being stationary due to structural breaks and unit root processes. We thus perform ADF tests on e in the two separate time periods, before and after 2001, and find that e is integrated of order I(1) in both. We thus chose to treat e as an I(1) process for the remaining analysis. As the real exchange rate, $e + cpif - cpi$, contains the nominal exchange rate, we also treat it as I(1).

We have now established that the variables we will be using have the desirable properties allowing us to estimate an empirical version of the theoretical relationship from chapter 3. However, there are some empirical issues we need to take into account when establishing an empirical representation of the theoretical relationship. What these are and which specifications are needed will be presented in the following chapter.

5 Empirical specification

In this chapter, we establish a dynamic specification of the theoretical relationship presented in chapter 3. The relationship will be dynamic in the sense that we assume shocks to be corrected over time through the equilibrating PPP and UIP relationships. This type of dynamic specification has been used by several other authors, including Akram (2002) and Bernhardsen and Røisland (2000). Dealing with time-series data containing a structural break, there are specific econometric challenges we have to take into account. We thus present suitable estimation methods for this kind of specification that are needed to be taken in order for the estimations to be empirically solid. One should, for example, take the possibility and effects of the variables having common movements over time, making them cointegrated, into account.

The chapter begins with presenting a dynamic representation of our theoretical framework. Following this, a discussion of cointegration and its implications for the possibility of a long run relationship is included. Finally, we discuss and present a suitable estimation framework allowing the effect of a change in the monetary policy to be taken into account.

5.1 A dynamic linear model

In order to establish a dynamic representation of the theoretical framework from chapter 3, we rewrite the relationship using our notation of the variables. In addition, the function f containing the oil price effects is linearized for the moment.

$$
\begin{aligned}
\Delta e_t = & -\alpha\big(e + cpif - cpi\big)_{t-1} - \Pi\big((RB - RBf)\big)_{t-1} \\
& + \sum_{j=0}^{p}\Big(\delta_j \Delta e_{t-1-j} + \beta_{1j}\Delta cpi_{t-j} + \beta_{2j}\Delta cpif_{t-j} + \beta_{3j}\Delta RB_{t-j} + \beta_{4j}\Delta RBf_{t-j} + \beta_{5j}\Delta FYI_{t-j} \\
& + \beta_{6j}\Delta NIBOR_{t-j}\Big) + \phi_0 oilp_{t-1} + \sum_{j=0}^{p}\phi_{j+1}\Delta oilp_{t-j} + c + v_t
\end{aligned}
\tag{5.1}
$$

The error term is captured by v_t which we assume to be iid, and c is a constant. We thus have an error correction model containing both autoregressive (AR) and distributed lag terms. In our context, this means that Δe_t could depend on its previous values. A shock could have lasting effects through expectations or through adjustments taking time. The distributed lags are represented by the lagged first difference terms of our exogenous variables. They capture the possibility of the exogenous variables x_t affecting the endogenous y_t though both its present and lagged value, i.e. they also have lasting effects. One can, for example, expect that the exchange rate at time t is not only affected by the oil price at time t but also that the history of previous prevailing oil prices could affect it.

5.2 Cointegration and long-run solutions

When dealing with time series, cointegration between variables might occur. This means there exists at least one linear combination of two or more I(1) variables being I(0). The existence of this allows us to utilize the Granger representation theorem proposed by Engle and Granger (1987). This states that the I(1) variables are cointegrated if, and only if, they have an ECM representation and vice versa. This allows us to separate short- and long-term effects from each other, as there will be a relationship with and one without the first differentiated terms. Such a long run relationship will be represented by the non-dynamic terms. In our context, this relationship can be found by setting all Δ terms to zero and solving for e, giving us the equilibrium exchange rate as:

$$e = -\left(cpif - cpi\right) - \frac{\Pi}{\alpha}\left((RB - RBf)\right) + \frac{\phi_0}{\alpha} oilp + \frac{c}{\alpha} \tag{5.2}$$

We thus have a relationship where the long-run equilibrium exchange rate is determined by the PPP and UIP relationships, as we assumed in chapter 3. However, the presence of cointegration is needed in order for this to hold. One simple way to test for the presence of cointegration in our system is to utilize the Granger representation theorem as proposed by Kremers et al. (1992), testing whether or not the coefficient of the error correction term is statistically significant and negative.[1] To see why testing the significance of this coefficient could indicate cointegration, we look at a vector error correction model (VECM) in the general form where y_t is a vector of the variables in a system.

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{p-1} \Delta y_{t-p+1} + u_t \tag{5.3}$$

This is a special case of a vector autoregressive (VAR) model under cointegration. Similar to the notation of the ADF-test, we have $\Pi = -(I_K - \alpha_1 - ... - \alpha_p)$ and $\Gamma_i = -(\alpha_{i+1} + ... + \alpha_p)$ for $i = 1, ..., p-1$ and I_k being the order of integration. As previously explained, the first differentiated terms can not by definition contain any stochastic trends if their non-differentiated terms are at most $I(1)$, and thus Πy_{t-1} is the only term in (5.3) that can contain any variables integrated of order $I(1)$. If we reject the null $H_0 : \Pi = 0$ against the alternative $H_a : \Pi > 0$ we can conclude that we have cointegration and a correcting process back towards an equilibrium level following shocks. If we can not reject the null, this does not mean we do not have any cointegrating relationship, only that we can not reject the null of there being none.

As we are only interested in the exchange rate as an endogenous variable, our model is a one-equation relationship of a VECM system of equations. In our context, we have an ECM repre-

[1] Note that when testing for the significance of this coefficient, we should use stricter p-values than those of a standard t-test. This is due to the alternative test for cointegration using an ADF-test may be too strict, and could, as Kremers et al. (1992) explains, ignore potential information in the Δ-terms, thus loosing power. The ECM test on α uses information more efficiently, and rejection of the null somewhere between the two distributions may be appropriate.

sentation (5.1) and a long run relationship if we can reject the null hypothesis $H_0 : \alpha = 0$ against $\alpha < 0$. If α is statistically significant and negative, we have an equilibrium correction over time back towards a long-run equilibrium exchange rate though the PPP and UIP relationships following a shock.

In addition to Kremers et al. (1992)'s test for cointegration, we can test for cointegration by using the method proposed by Johansen (1995), providing two test statistics for cointegration. These rely on the number of lags included, determined by using the same information criterion as earlier. In addition to the two tests, we report the optimal number of cointegrating equations based information criteria model selection. This is done for the two periods separate and as a whole, and the results can be seen in table B.2. Although giving slightly differing results, the tests suggest that we have at least a cointegrating rank of $r = 1$, suggesting that the use of an error correction model will be a good choice.

5.3 Switching models

In several economic time series, the variables may seem to be subject to substantial changes in their behavior between time periods. This could happen through changes in its mean value, volatility or dependency on its previous values. Changes like this are referred to as structural breaks, i.e. the data has a clear pattern which is replaced at some certain point of time. This effect may be permanent or only temporary, and could reflect changes in the real world politics, financial panics etc. Permanent changes are often referred to as regime shifts. As mentioned, we are looking at a time span where the Norwegian Central bank went from a managed float to having an inflation targeting regime. Based on the graphical displays of the exchange rate and the tests performed, there is strong evidence of a structural break in our data. In addition, unit root tests have, as mentioned, low power when subject to a structural break, and using an empirical estimation method taking this increase in the exchange rate volatility into account is appropriate.

We will thus use a Markov-switching model as part of our estimation process. This approach is explained in Lütkepohl and Krätzig (2004), and splits the data into s possible states, calculating the probability of the process being in state s in period t based on the state which prevailed in time period $t-1$ and those before that. Based on this, the estimated effect of the variable(s) allowed to switch is calculated for each state. We can illustrate this method by looking a simple case of two possible states, $s = 1, 2$. If we denote the probability of a variable z_t being in state 1 in period t as $prob[z_t = 1|z_{t-1} = 1] = p_{11}$, then the probability of switching from state 1 to state 2 from period $t-1$ to t is $prob[z_t = 2|z_{t-1} = 1] = 1-p_{11} = p_{12}$. Further, the probability of staying in state 2 between the two period equals $prob[z_t = 2|z_{t-1} = 2] = p_{22}$, and the probability switching from state 2 to state 1 between $t-1$ and t equals $prob[z_t = 1|z_{t-1} = 2] = 1 - p_{22} = p_{21}$. In this context, one would estimate one across-the-board equation for the non-switching variables, with two state dependant sub-equations containing the estimated coefficients of the switching variables. Generally, the transition probabilities can be express with the following matrix when we have s possible states.

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1s} \\ p_{21} & p_{22} & \cdots & p_{2s} \\ \vdots & \vdots & \ddots & \vdots \\ p_{s1} & p_{s2} & \cdots & p_{ss} \end{bmatrix}$$

Where p_{ij} is the probability of moving from state i to state j between the two time periods, and $\sum_{j=1}^{s} p_{ij} = 1 \ \forall \ i$. The results from estimating a Markov switching model gives us the estimated effect of our exogenous variables in the different states following structural breaks. It thus can show us the effect of the oil price before and after the change in Norwegian monetary policy. The procedure also produces the transition probabilities, indicating the probability of being in either of the states, i.e. indicating which of the s states the regression belongs to at any given time. Another possibility of the Markov switching estimations, which we will utilize, is to look at the possibility of the variance changing between the different states. This is reasonable to expect when there is a clear change in the volatility of our data between the states.

We have thus established a dynamic framework for estimating our linear model, and one where we allow the parameters to change with structural breaks. In the following chapter, we utilize these in order to estimate an empirical relationship based on the theories established in chapter 3.

6 Empirical results

Following the empirical specifications of the last chapter, we estimate an ECM for the three time spans to look at the effect of the oil price on the exchange rate, and whether or not this effect has changed following the introduction of inflation targeting in the first quarter of 2001. Our analysis starts with a ordinary least squares (OLS) estimation of an unrestricted linear model including present and lagged values of our explanatory variables. However, following the estimation results, we suspect that the estimating power could increase by restricting the model. This is done by only including the lagged values of all first differentiated terms except the oil price. The reasoning behind and estimation results of doing this is presented along with a comparison of the two models. We also find the long-term relationships and include some post-estimations tests for heteroscedasticity and autocorrelation for both models. In order to account for the change of monetary policy regime, a Markov-switching model is presented with a discussion of its estimation results, state predictions, and long term solution. Looking at some real events, we find evidence of asymmetrical oil price effects. To account for this, we motivate and perform both OLS and Markov-switching estimations of a non-linear model. After discussing the non-linear results, we end the chapter by comparing the model prediction power on some well-known events in all our estimated relationships.

6.1 Dynamic linear model in different time periods

We begin our analysis by estimating the following dynamic model, where we include all the first differentiated terms at both times t and $t-1$. In order to capture the longer lasting effects of previous exchange rates and oil price, two lags of both are included.

$$
\begin{aligned}
\Delta e_t = & -\alpha\big(e + cpif - cpi\big)_{t-1} - \Pi\big((RB - RBf)\big)_{t-1} + \delta_0 \Delta e_{t-1} + \delta_1 \Delta e_{t-2} \\
& + \sum_{j=0}^{1} \Big(\beta_{1j} \Delta cpi_{t-j} + \beta_{2j} \Delta cpif_{t-j} + \beta_{3j} \Delta RB_{t-j} + \beta_{4j} \Delta RBf_{t-j} + \beta_{5j} \Delta FYI_{t-j} \\
& + \beta_{6j} \Delta NIBOR_{t-j}\Big) + \phi_0 oilp_{t-1} + \phi_1 \Delta oilp_t + \phi_2 \Delta oilp_{t-1} + \phi_3 \Delta oilp_{t-2} + c + \upsilon_t \qquad (6.1)
\end{aligned}
$$

The interpretation of these coefficients is as follows. A 1% increase in Δcpi_{t-j} implies a β_{1j} change in the growth rate of the exchange rate. This is also the case for $\Delta cpif_{t-j}$ and $\Delta oilp_{t-1}$ for their respective coefficients. Concerning ΔRB_{t-j}, ΔRBf_{t-j}, ΔFYI_{t-j} and $\Delta NIBOR_{t-j}$, a 1 unit increase in either variable implies a $\beta_{ij} \times 100$ change in the growth rate of the exchange rate. The latter comes from the interest rates and FYI not being in logarithms, and β_{ij} corresponds to the variable's respective coefficients.

The term $(e+cpif-cpi)_{t-1}$ gives the error correction of the model, and its coefficient say something about the strength of the movement back to equilibrium following a shock. Following a situation like this, approximately $\alpha * 100\%$ of the deviation from the long-run equilibrium is corrected through $(e + cpif - cpi)$ at each t, i.e. each quarter. This does, however, rely on the coefficient of the real exchange rate being statistically significant and negative, implying cointegration and error correction through the Granger representation theorem as explained earlier. Together with $(RB-RBf)$ and $oilp$, $(e+cpif-cpi)$ provides the long-run equilibrium exchange rate under the assumption of the PPP and UIP relationships holding in the long run. The OLS estimation results of this model are reported in the first three columns of table 6.1. The last three columns of the table correspond to the restricted model, which will be described later. As mentioned earlier, negative coefficients correspond to an appreciation of the NOK-ECU exchange rate, while positive coefficients indicate a depreciation.

Table 6.1: OLS estimation of the unrestricted and unrestricted dynamic linear model.

	Unrestricted			Restricted		
Time-period	1 &2	1	2	1 & 2	1	2
Δe_{t-1}	0.120	-0.0165	0.130	0.124	-0.0473	0.114
	(0.106)	(0.188)	(0.149)	(0.102)	(0.174)	(0.143)
Δe_{t-2}	0.174	-0.407*	0.381***	0.170	-0.431**	0.420***
	(0.107)	(0.204)	(0.136)	(0.104)	(0.183)	(0.141)
$(e+cpif-cpi)_{t-1}$	-0.170***	-0.181	-0.137**	-0.115**	-0.107	-0.162***
	(0.0574)	(0.172)	(0.0664)	(0.0493)	(0.142)	(0.0588)
$(RB-RBf)_{t-1}$	-0.000892	0.00138	0.00316	0.00162	0.000423	0.00592
	(0.00251)	(0.00523)	(0.00433)	(0.00213)	(0.00396)	(0.00403)
ΔFYI_t	0.0170	-0.0868	0.0424			
	(0.0857)	(0.154)	(0.109)			
ΔFYI_{t-1}	-0.00538	-0.0173	-0.0143	0.0282	0.0591	-0.0107
	(0.0863)	(0.166)	(0.112)	(0.0736)	(0.126)	(0.0979)
$\Delta NIBOR_t$	-0.00299	-0.00449	-0.0293***			
	(0.00378)	(0.00440)	(0.0106)			
$\Delta NIBOR_{t-1}$	0.00152	0.000715	0.0153	-0.000300	0.00330	-0.00285
	(0.00374)	(0.00477)	(0.0105)	(0.00348)	(0.00408)	(0.00837)
Δcpi_t	0.287	0.381	0.230			
	(0.367)	(0.876)	(0.438)			
Δcpi_{t-1}	0.341	0.0796	0.436	0.195	-0.144	0.317
	(0.359)	(0.820)	(0.406)	(0.347)	(0.778)	(0.401)
$\Delta cpif_t$	-1.202**	-1.254	-0.403			
	(0.551)	(1.352)	(0.722)			
$\Delta cpif_{t-1}$	-0.181	0.851	-0.359	0.415	0.642	0.283
	(0.558)	(1.241)	(0.779)	(0.457)	(1.185)	(0.538)
ΔRB_t	0.000829	0.0144	0.000410			
	(0.00730)	(0.0110)	(0.0113)			
ΔRB_{t-1}	0.000386	-0.00148	0.00771	0.00337	-0.00498	-0.00151
	(0.00741)	(0.0125)	(0.0113)	(0.00690)	(0.0110)	(0.0103)
ΔRBf_t	0.00132	-0.0189	0.00651			
	(0.00643)	(0.0123)	(0.00804)			
ΔRBf_{t-1}	0.00512	0.00745	0.00230	0.00402	0.00868	0.00735
	(0.00622)	(0.0119)	(0.00816)	(0.00580)	(0.0114)	(0.00764)
$oilp_{t-1}$	-0.00115	-0.0230	0.00880	0.00153	-0.0252	0.0115
	(0.00324)	(0.0217)	(0.00838)	(0.00289)	(0.0193)	(0.00824)
$\Delta oilp_t$	-0.0665***	-0.0531*	-0.0658***	-0.0803***	-0.0733***	-0.0926***
	(0.0166)	(0.0301)	(0.0231)	(0.0138)	(0.0254)	(0.0179)
$\Delta oilp_{t-1}$	0.00584	0.00472	0.0372	-0.00461	-0.00433	0.00458
	(0.0185)	(0.0207)	(0.0289)	(0.0163)	(0.0205)	(0.0246)
$\Delta oilp_{t-2}$	-0.00779	-0.0380	0.0107	-0.00929	-0.0313	0.0225
	(0.0157)	(0.0240)	(0.0245)	(0.0147)	(0.0213)	(0.0223)
_cons	0.367***	0.450	0.251	0.236**	0.298	0.291**
	(0.128)	(0.413)	(0.150)	(0.107)	(0.345)	(0.130)
N	104	41	63	105	41	64

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The coefficient of $(e + cpif - cpi)_{t-1}$ indicates the existence of a long-term relationship if both negative and statistically significant. This is the case for all our estimations, except in the first time period, where it is statistically insignificant in both models, i.e. we can not with statistically sufficient confidence say that there is cointegration in the first period through testing the significance of α. However, as the coefficient is negative and the Johansen test performed earlier suggested cointegration in the first period, we proceed the analysis under the assumption of there existing error correction dynamics, but keep the lack of evidence in mind. Following the procedure explained earlier, we set all first differentiated terms to zero and solve for e in order to get the long-term solution. For the unrestricted model, this becomes the following.

$$e_{1\&2} = 2.159 + (cpi - cpif) - 0.00325(RB - RBf) - 0.00677oilp$$
$$e_1 = 2.486 + (cpi - cpif) - 0.00762(RB - RBf) - 0.127oilp$$
$$e_2 = 1.832 + (cpi - cpif) - 0.0231(RB - RBf) + 0.0642oilp$$

We thus have a long-term solution for the equilibrium nominal exchange rate containing price differentials, interest rate differentials and the logarithm of the oil price. As explained in the data description, higher inflation in Norway than in the EU should, ceteris paribus, depreciate the nominal exchange rate, while a positive interest rate differential should appreciate the exchange rate. Our long term solution fits well with these expected effects and suggests that the appreciating effect of the interest rate differential was greater in the time period after inflation targeting was introduced. Concerning the effect of the oil price, the coefficient has the opposite effect of what we would expect in the second time period. As for the two other periods, it has an appreciating effect as expected. However, both the coefficient of $oilp_{t-1}$ and the interest rate differential are never statistically significant, and we take their estimated long-run effects with a pinch of salt. This would indicate that the long-run exchange rate given by the long run solution is not very dependent on the oil price or interest rate differentials. Rather, the estimation results suggest that the long-run equilibrium exchange rate is mostly influenced by the price difference between Norway and the EU. That the inflation has a lot to say for the equilibrium exchange rate is not very surprising. The long term exchange rate is derived from the real exchange rate and inflation targeting builds on the assumption of that maintaining price stability is the best practise policy for sustaining both economic growth and exchange rate stability. This also implies that there is a one-to-one relationship between the long-term exchange rate and the difference in prices. If the price difference between Norway and the EU increases by 1%, the equilibrium exchange rate would also increase by 1%. We thus have strong evidence of PPP holding in the long run under the inflation targeting monetary regime, while the evidence of this is less clear under the managed float monetary policy regime. In the latter, the long-run equilibrium exchange rate may be decided by its allowed range of fluctuations.

In order to capture the long-term effects in the exchange rate, we include two lags of Δe as it might take time for the exchange to adjust following a shock. Although insignificant coefficients at $t-1$, we see that there is opposing effects in the two separate time periods. In the first time-period, a shock in the lagged exchange rate terms will cause a correcting effect back towards the initial level, while shocks seem to have lasting effects in the shock's direction in the second time period. One possible explanation could be that Norges bank would to a larger degree try to intervene in order to correct the exchange rate back to its initial range of values under a managed float regime than under inflation targeting. This could also help to explain why the coefficient of the real exchange rate, $(e+cpif-cpi)_{t-1}$, is not statistically significant in the first time period, while it is in the whole and second time period. The significance in the second time period could influence the result for the whole time period and, as mentioned, there is stronger evidence suggesting an equilibrium correction through $(e+cpif-cpi)_{t-1}$ following the introduction of inflation targeting than under the managed float monetary policy regime.

As mentioned, the coefficient of $(RB-RBf)_{t-1}$ is statistically insignificant for all time spans, indicating that interest rate deviations do not have a statistically significant equilibrating effect on the exchange rate. However, there are other statistically significant effects of interest rates. $\Delta NIBOR$ has a statistically significant negative effect in the second time-period, and although insignificant, negative effects in the two remaining time-periods. This makes sense as one would expect increased monetary interest rates to increase demand for the Norwegian Krone, causing an appreciation of the Krone exchange rate. The coefficient of ΔRB, on the other hand, is not significant in any time-periods, but this could be a result of a high correlation between ΔRB and $\Delta NIBOR$, suggesting that the effect may be caught up in $\Delta NIBOR$.

Concerning the estimated values of α, an approximate 17%, 18.1% and 13.7% of a deviation from the long-run equilibrium exchange rate is corrected through $(e+cpif-cpi)_{t-1}$ per quarter in the whole, first and second time period respectively. These estimated speed of adjustment coefficients are rather small, and one might have expected larger values for a variable which seem to move rapidly following shocks such as the exchange rate. Further, we can use this to calculate the half-life of the deviations from the long-term equilibrium following a shock as $T = \frac{ln(0.5)}{ln(1-\alpha)}$.[1] This is a measure of how many quarters it takes to correct half of a deviation from the equilibrium exchange rate. Based on the estimated α's we calculate a half-life of 3.72, 3.47 and 4.70 quarters in the whole, first and second time period respectively. Although this may seem long, it is shorter than the general consensus in the literature of a three to five year half-life following their estimated values of the speed of adjustment coefficient between 0 and 0.1.[2] One explanation for this seemingly long half-life could be, as Rogoff (1996) explains, the persistence of nominal variables such as wages and prices.

Looking at the effects of the oil price, $\Delta oilp_t$ gives the short-term effect of changes in the oil price. A 1% change in $\Delta oilp_t$ implies a ϕ_1% change in Δe_t. The estimated coefficient of the first differentiated oil price is, at least weakly statistically significant in all periods, while its lagged values included to capture adjustment effects are not. The sign of the coefficient of $\Delta oilp_t$ is as expected, suggesting that an increase in the oil price will appreciate the exchange rate as explained through the Harrod-Balassa-Samuelson effect. This oil price effect effect is statistically significant at a 1% critical level in the whole and second time period, but only at 10% in the first time period. In addition, the oil price effect in the second time period, -0.0658, is greater in absolute value than the effect in the first time period at -0.0531. Looking at a one standard error increase in the oil price, this implies a 0.011% appreciation of the exchange rate in the whole period. For the two separate time periods, the equivalent effect is at 0.0084% for the first and 0.011% for the second time period.[3] We thus find that a typical movement in the oil price had larger effects on the exchange rate in the second time period than in the first. This difference of the estimated effects between the periods makes sense as it's only in the second time period

[1] Based on Chortareas and Kepetanios (2012), we derive this half-life measure from $(1-\alpha)^T = 0.5 \rightarrow T = \frac{ln(0.5)}{ln(1-\alpha)}$.

[2] See, for example, Chortareas and Kepetanios (2012), Taylor and Taylor (2004) or Rogoff (1996).

[3] Note that the standard error of $\Delta oilp$ is not equal across the board, but equals 0.162, 0.158 and 0.165 for the whole, first and second time period respectively.

that the exchange rate was freely floating, suggesting a stronger effect than when the exchange rate was not. We thus find evidence of the oil price having larger effects on the Krone exchange rate under the inflation targeting monetary policy regime than under a managed float monetary policy. The coefficient of $oilp_{t-1}$ is not statistically significant for any time period. If it were, it would have indicated a ϕ_0% change in Δe_t following a 1% change in $oilp_{t-1}$. Although insignificant, it is worth noting that it has opposite signs in the first and second time period. This could indicate that the long-run exchange rate was more negatively dependent on previous oil prices under the managed float regime than under today's inflation targeting regime.

The remaining terms are dynamic terms of interest rates, inflation and our measure of the current account balance relative to GDP. These are included as control variables to make sure we don't get biased estimates due to omitted variables, as we expect them to affect the exchange rate. Most of them are statistically insignificant, except $\Delta cpif_t$ in the whole period which is negative and statistically significant. The latter is somewhat puzzling, as it is not significant in period 1 and 2 separated. This could, however, indicate that the effects of prices are long term, as suggested by the long-term PPP relationship. We can test whether or not all the estimated effects of our explanatory variables are equal in the two separate time periods by performing a Chow test comparing the two relationships against the whole period. The null hypothesis in this test is $H_0 : \delta_1^{P1} = \delta_1^{P2}, ..., \beta_1^{P1} = \beta_1^{P2}, \beta_2^{P1} = \beta_2^{P2}, \ldots, \phi_3^{P1} = \phi_3^{P2}$, which is tested against the alternative that at least one of the coefficients are not equal.[4] Our results of performing this test indicate that at least one of the coefficients in the two separate time periods are, in fact, statistically significantly different from each other. Although the test does not specifically say anything about the oil price effect, the results could indicate that the estimated ϕ_1s are statistically different between the two periods, as this coefficient is one of the few statistically significant in both time periods.

Although our analysis so far is in favor of what we expected, i.e. that increasing oil prices has an appreciating effect on the exchange rate and that this effect is larger under inflation targeting than under the managed float regime monetary policy regime, we suspect that the estimations can be improved. This is partially based on the lack of statistical significance in the control

[4]The results of all Chow tests can be found in table B.6 of the appendix, and P1 and P2 corresponds to the first and second time period respectively.

variables. To deal with this we decide to restrict the model somewhat, which will be discussed in the following section.

6.1.1 Restricting the linear model

As mentioned, we restrict the model due to the persisting insignificance of the explanatory variables. We test whether or not we can reject the null of all the first difference terms, ΔFYI_t, $\Delta NIBOR_t$, Δcpi_t, $\Delta cpif_t$, ΔRB_t, ΔRBf_t, parameters being zero at the same time, i.e. that we can exclude them from the model. This is also done as we expect that this range of variables needs more time in order to affect the exchange rate. Performing a standard F-test of overall significance of the coefficients of the Δ terms, we find that we can not reject the null, suggesting that the combined effects of the variables equals zero.[5] We thus restrict the model accordingly to the following and the estimation results are reported in the last three columns of table 6.1.

$$\begin{aligned}\Delta e_t = & -\alpha\big(e + cpif - cpi\big)_{t-1} - \Pi\big((RB - RBf)\big)_{t-1} + \delta_0 \Delta e_{t-1} + \delta_1 \Delta e_{t-2} \\ & + \beta_1 \Delta cpi_{t-1} + \beta_2 \Delta cpif_{t-1} + \beta_3 \Delta RB_{t-1} + \beta_4 \Delta RBf_{t-1} + \beta_5 \Delta FYI_{t-1} + \beta_6 \Delta NIBOR_{t-1} \\ & + \phi_0 oilp_{t-1} + \phi_1 \Delta oilp_t + \phi_2 \Delta oilp_{t-1} + \phi_3 \Delta oilp_{t-2} + c + v_t \end{aligned} \tag{6.2}$$

Based on the estimation results, we follow the same procedure as earlier to calculate the long-term solution for the equilibrium exchange rate.

$$\begin{aligned} e_{1\&2} &= 2.052 + \big(cpi - cpif\big) + 0.0141\big(RB - RBf\big) + 0.0133 oilp \\ e_1 &= 2.785 + \big(cpi - cpif\big) + 0.00395\big(RB - RBf\big) - 0.843 oilp \\ e_2 &= 1.796 + \big(cpi - cpif\big) + 0.0365\big(RB - RBf\big) + 0.0710 oilp \end{aligned}$$

Comparing these to the long-term solution of the unrestricted model, we see some changes in the signs of the coefficients. Both the price and interest rate differentials have positive coefficients. This is as expected for the difference in prices, but the opposite of what one would

[5]The test is rejected at a 45% level of significance, while performing the same F-test but including $\Delta oilp_t$ is clearly rejected at 0% level of significance. We thus keep the first difference of the oil price in the rest of the analysis.

expect from the interest rate difference. The latter is also the case for the coefficient of $oilp$ in the whole and second time period. However, neither the underlying coefficients of the interest rate difference nor $oilp$ is statistically significant for any time period in this model either, and we should thus not interpret too much from them. As with the long-term solution of the unrestricted model, our estimations indicate that the difference in prices has been the driving force in determining the equilibrium exchange rate. Concerning whether or not there is evidence of the existence of long-term solutions, α is statistically significant and negative in the whole and second time period. As for the unrestricted model, however, we include the long-term solution for the first time period as the estimated α is negative and the Johansen test performed earlier suggested cointegration. Again, there is stronger evidence of the equilibrium exchange rate being decided through the PPP condition under the inflation targeting monetary policy than under the managed float monetary policy.

Looking at the short run estimations, the estimated value of α is lower in the restricted model than in the unrestricted one, suggesting that less of the deviation from the long-term equilibrium exchange rate is corrected through the PPP condition per quarter. This decrease in the speed of adjustment coefficients results in longer half-life times of 5.67, 6.12 and 3.92 quarters for the whole, first and second time period respectively. Although longer than in the unrestricted model, this is still shorter than the three to five year half-life suggested by previous literature. Further, both the interest rate difference and all control variables are statistically insignificant across the board as in the unrestricted model. The estimated coefficients of the lagged exchange rate are statically insignificant across the board at the first lag, and only statistically significant at 5% for the two time periods separately at the second lag. Their signs suggests that shocks to the exchange rate are corrected through its lagged values in the pre-2001 period while having persisting effects following the introduction of inflation targeting.

Although quite similar models, the estimated effect from the oil price is greater in absolute values and statistical significantly stronger in the restricted model than in the unrestricted one. A 1% increase in $\Delta oilp_t$ implies an approximately 0.08%, 0.07% and 0.09% decrease in the value of Δe_t in the whole, first and second time period respectively. Looking at a one standard error increase in $\Delta oilp$, implies an approximately 0.0129%, 0.0116% and 0.0153% appreciation of the exchange rate in the whole, first and second time period respectively. Again, we see that typical movements in the oil price had a larger effect on the exchange rate after inflation targeting was introduced than before 2001. We also see that, although insignificant, the coefficient of $oilp_{t-1}$ in the restricted model is greater in absolute value than in the unrestricted for all time periods. Based on our estimations, we conclude that the oil price had more to say on the exchange rate movements after inflation targeting was introduced, and that the oil price has more to say in the restricted model than in the unrestricted one. One can thus argue that the restricted model may fit our theoretical model better than the unrestricted one. However, performing a chow test on the equality of the coefficients in the two separate time periods, the rejection of the null hypothesis is slightly less clear than in the unrestricted model.[6] As earlier, the test results could indicate that the oil price effects are, in fact, different before and after 2001.

Further, we need to perform some tests on our estimations to further check their statistical power. Classical linear regressions on time series rely on the assumption of no autocorrelation in order for the estimators to be the best linear unbiased estimator (BLUE). This relies on the estimations to be efficient, which is the case when the estimated error terms are uncorrelated with each other, i.e. that the error term $\hat{u}_t$, is independent of its previous values, $\hat{u}_{t-1}, \hat{u}_{t-2}, \ldots, \hat{u}_{t-i}$. If this is not the case, our estimations will not be efficient such that the standard errors may be wrong and normal inference no longer applies. Similar to that of stationarity, autocorrelation can be indicated and detected through looking at a graphical time display of the error term. A cyclical residual plot over time indicates autocorrelation, while no clear pattern could indicate no autocorrelation. Although not reported, we looked at such graphical displays and found no visual evidence of there existing any autocorrelation in either model. However, these visual checks may not be very clear in all cases, and we must rely on more formal empirical tests. For linear regressions containing lags, this can be done using the alternative Durbin test, proposed by Durbin (1970). This test for autocorrelation in the error terms of a general AR(p) process, $u_t = p_1 u_t + \cdots + p_p u_{t-p} + \eta_t$ with a null hypothesis $H_0 : p_1 = 0, \ldots, p_p = 0$ against the alternative of at least one of p_p being non-zero. However, as noted, there exist a structural break in our data. As the exchange rate becomes more volatile following this break, we suspect that the variance of

[6]The null hypothesis of all β_j being equal in the two relationships are rejected at a 2.2% level of significance in the unrestricted model, while at a 6.7% level of significance in the restricted model.

our estimations may not be constant over time, i.e. that we have heteroscedasticity. We test for this using the Breusch-Pagan test for heteroscedasticity on our regression, which clearly rejects the null of the variance being constant in the whole time period, while we clearly can not reject the null in the two separate time periods. Based on this, we perform the alternative Durbin test on an autoregressive conditional heteroskedasticity (ARCH) process on the model for the whole period, while we perform the normal alternative Durbin test for the separate time-spans. The results of performing these test can be seen in table B.3 in the appendix. We find that we can not reject the null hypothesis of there being no autocorrelation on any of our two lags, in either model.[7] We also re-estimate the two models for the whole period using robust standard errors as there are evidence of heteroscedasticity. However, the changes in the standard errors are not sufficient to alter the outcome of any of our tests for statistical significance, and our conclusion on the estimations remain the same.

We thus conclude with there existing strong and statistically sufficient evidence of the oil price affecting the exchange rate, and that this effect became stronger after the inflation targeting monetary policy regime was introduced in 2001. A positive shock in the oil price will cause an appreciation of the exchange rate, and is followed by corrections back towards its equilibrium level through the PPP condition. Concerning the long-run equilibrium exchange rate, we find stronger evidence of the PPP condition holding in the long run for the post-2001 time period than before 2001, and that the oil price only affects the exchange rate in the short run. Due to the evidence of the oil price effect depending on the monetary policy regime, we continue our investigation with Markov-switching estimations. Although our oil price effect is more statistically significant and greater in the restricted model, the R^2 of the restricted models are slightly lower than in the unrestricted ones. This is a measure of goodness of fit and gives how much of the variation in our dependent variable can be explained by our explanatory variables. This would suggest the unrestricted model to be a better choice. We do, however, proceed with the restricted model for the Markov-switching estimation, as the restricted model proves to be, by far, better behaving and preferred by our model selection criteria.

[7]The optimal number of lags used to test for autocorrelation are found through model selection criteria on a model containing all variables.

6.2 Markov-Switching estimation results

When performing the Markov-Switching estimation, certain assumptions were made in order to get a good behaving model. As our main goal of this research is finding the relationship between the oil price and the exchange rate, we choose to only let the oil price terms and the constant to have switching effects. This is done as the UIP and PPP are long term movements, which we assume to hold over the whole time period. Further, we expect the remaining short-term effects of current account deficit relative to GDP, interest rates, and inflation to be independent of the monetary regime. The effect of the oil price, on the other hand, is allowed to vary with the state in order to capture the change of monetary regime. This implies that we assume the correcting terms and control variables to behave independently of monetary policy. Another reason why we chose to only let the oil price switch is that including more variables make the estimation too complex given our data.

As mentioned, we use the restricted version of our model as this gives us a better behaving and preferred model based on our model selection criterion.[8] This also provides us with very stable state predictions, giving the estimation better explanatory power than the unrestricted one. Further, as the monetary regime is only changed once within our time period, from a managed float to the more flexible inflation targeting regime, we choose to estimate the model using two possible states. As mentioned earlier, we see a clear increase in the volatility of the exchange rate following the introduction of inflation targeting. We thus let the variance of the model to switch in order to catch up this change in volatility. The Markov-switching model can be represented by the following equation where the state of the model is denoted by $s = 1, 2$.

$$\begin{aligned}\Delta e_t = & -\alpha\big(e + cpif - cpi\big)_{t-1} - \Pi\big((RB - RBf)\big)_{t-1} + \delta_0\Delta e_{t-1} + \delta_1\Delta e_{t-2} \\ & + \beta_1\Delta cpi_{t-1} + \beta_2\Delta cpif_{t-1} + \beta_3\Delta RB_{t-1} + \beta_4\Delta RBf_{t-1} + \beta_5\Delta FYI_{t-1} + \beta_6\Delta NIBOR_{t-1} \\ & + \phi_{0s} oilp_{t-1} + \phi_{1s}\Delta oilp_t + \phi_{2s}\Delta oilp_{t-1} + \phi_{3s}\Delta oilp_{t-2} + c_s + \epsilon_{st} \end{aligned} \tag{6.3}$$

[8]This model is preferred by both AIC and SBIC over both a Markov-switching of the unrestricted model and one with only non-lagged first differentiated explanatory variables.

The estimation results of this Markov-Switching model is reported in table 6.2, with the estimated coefficients and standard errors of the variables covering the whole period reported on the top, before the estimated state dependant oil price effects, variance and state predictions are reported below.

Table 6.2: Markov-Switching estimation of the restricted linear model

Δe_t	coefficient	standard error		
Δe_{t-1}	0.165	(0.0956)		
Δe_{t-2}	0.359**	(0.101)		
$(e+cpif-cpi)_{t-1}$	-0.148***	(0.0418)		
$(RB-RBf)_{t-1}$	0.00210	(0.00240)		
ΔFYI_{t-1}	-0.00771	(0.0401)		
$\Delta NIBOR_{t-1}$	0.00257*	(0.00138)		
ΔRB_{t-1}	-0.000628	(0.00340)		
ΔRBf_{t-1}	-0.00463	(0.00374)		
Δcpi_{t-1}	0.418	(0.264)		
$\Delta cpif_{t-1}$	0.0181	(0.332)		
	State 1		State2	
$oilp_{t-1}$	-0.0420***	(0.0138)	0.00225	(0.00397)
$\Delta oilp_t$	0.0000881	(0.0129)	-0.0914***	(0.0149)
$\Delta oilp_{t-1}$	0.0198**	(0.00925)	0.0204	(0.0181)
$\Delta oilp_{t-2}$	0.0137	(0.009808)	0.0153	(0.0174)
constant	0.433***	(0.120)	0.300***	(0.0908)
σ_1^2	0.00416		σ_2^2	0.0200
p11	0.985		p12	0.0155
p21	0.00831		p22	0.992

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As in our OLS estimation, we see that the coefficient of $(e-cpif-cpi)_{t-1}$ is statistically significant and negative, implying that a long-term solution of the equilibrium exchange rate exists. Following the procedure previously used, we find the long term solution for each of the states. For the low-volatility state, this becomes.

$$e = 2.928 + \left(cpi - cpif\right) + 0.0142\left(RB - RBf\right) - 0.284 oilp$$

While for the high-volatility state it becomes the following.

$$e = 2.030 + (cpi - cpif) + 0.0142(RB - RBf) + 0.0152oilp$$

Similar to the long-term solution of the linear model, some of the estimated effects are not quite what would be expected based on the economic theory. The coefficient of the interest rate differential is positive, while we would expect a negative coefficient. For the long term solution of state two, we also see that the oil price has an estimated depreciating effect. However, similar to the linear model, neither of these underlying coefficients are statistically significant, and the counter-intuitive effects should be taken with a pinch of salt. For state one, the oil price has an estimated appreciating and statistically significant effect. In the latter, an increase in the oil price by 1% would imply a 0.284% decrease in the long-run equilibrium exchange rate, i.e. the long-run equilibrium exchange rate will appreciate by 0.284% following a 1% increase in the long-run oil price.

Looking at the short run estimations, the estimated value of the speed of adjustment coefficient, α, equals -0.148 which further result in a half-life of 4.33 quarters. This means that it takes approximately 4.3 quarters to correct half of a deviation from the long-run equilibrium exchange rate in either state. Further, the coefficient of Δe_{t-2} is statistically significant and positive, and the coefficient of the money market interest rate is weakly statistically significant. The latter could be a part of the reason why the interest difference effect is statistically insignificant. The coefficients of the remaining non-switching variables do not have any statistically significant effects.

Before looking at the estimated short-run oil price effects, an explanation of the state probability is appropriate. $p11$ and $p22$ have rather large estimated values, while $p12$ and $p21$ have rather low values. This means that there is a low probability of the model switching from one state to the other at any point in time, i.e. we have very stable states, indicating a good fitting model. Further, we see that $\sigma_1^2 < \sigma_2^2$. State two has a larger variance than state one and is the more volatile one. The model should thus belong to this state in the time periods where we had a more volatile exchange rate, i.e. after 2001. To illustrate how well fitting the estimations are, we display the probability of the model belonging to state two at each point of time in the following graph, where $p22$ is illustrated by the solid line.

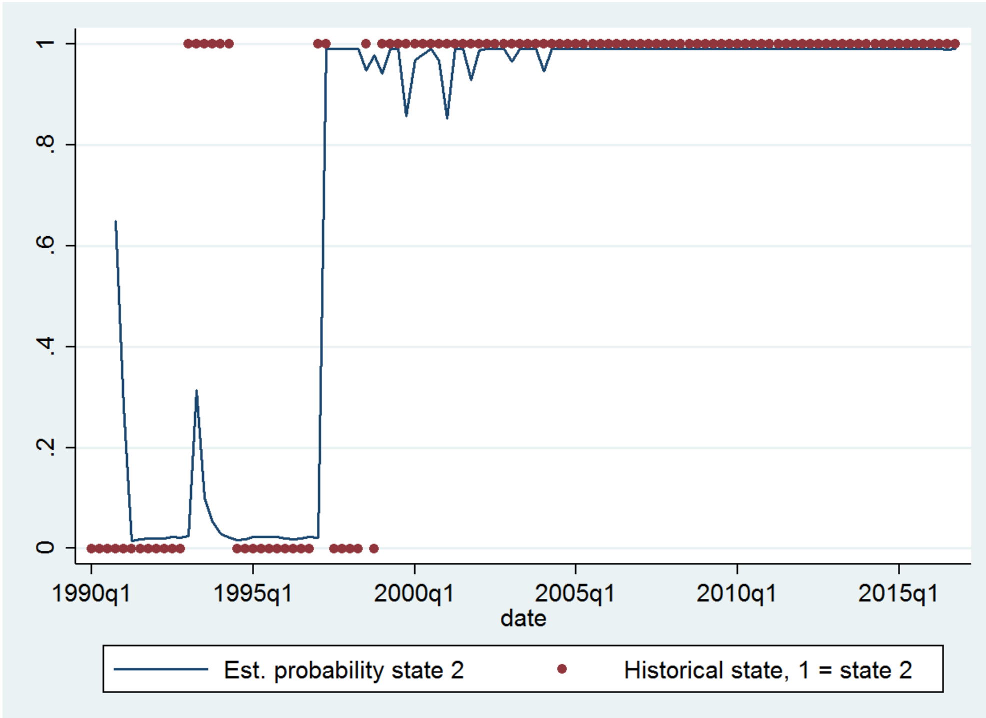

Figure 6.1: State prediction and historical states.

In addition, we have included an indicator of which state the exchange rate actually belonged to. The latter is represented by the red dots in figure (6.1), corresponding to a dummy variable equaling 1 if the exchange rate was freely floating, and zero if not. The dummy is based on actual historical events about the monetary policy described by Alstadheim (2016). He provides a summary of the Norwegian monetary history from 1990 throughout the end of our time period. From 1990 till 1992, Norges Bank established a peg of the Norwegian Krone against the ECU, while they practiced a managed float regime from the third quarter of 1993 to the fourth quarter of 1998. In the transition between the two, the exchange rate was freely floating following a range of speculative attacks. In addition, further speculative attacks and depreciation pressures forced Norges bank to cease their market interventions in shorter periods from 1997 up till 1999, implementing in practice a free floating exchange rate in these periods. Another interesting observation is that although Norges bank officially introduced inflation targeting in the first quarter of 2001, one could argue that it was de facto implemented by Svein Gjedrem following a statement of his in 1999. He was the chief of the Norwegian central bank at the time, and said that in order to maintain the managed float against the Euro, Norway had to have the same inflation as the ECB. From graph 6.1, we see that our model's state prediction reacts to all of these events and that the model has a clear predicted change from state one to state two at the first quarter of 1997, indicating that this was the start of the free floating exchange rate period. The latter could point in the direction of inflation targeting actually being implemented by Gjedrem in 1999 and not by Norges Bank officially in 2001, and that the market reacts to the actions that Norges Bank take, and not necessary what its official statements say. We have thus established that state one belongs to the time period of the managed float regime, while state two corresponds to the time period of inflation targeting or other events causing a freely floating exchange rate. Further, a look at the effect of the oil price given each of these states will now be appropriate.

In state one, the coefficient of $oilp_{t-1}$ is statistically significant and negative, implying that a 1% increase in $oilp_{t-1}$ would cause a 4.20% appreciation of the exchange rate. For state two, this effects is statistically insignificant while a 1% increase in $\Delta oilp_t$ implies a 0.0914% statistically significant appreciating effect on Δe_t. A one standard error increase in $oilp$ in state one wold appreciate the exchange rate by 3%. Similarly, if $\Delta oilp$ increase by one standard error, the exchange rate would appreciate by 0.0147% if in state two. Although statistically insignificant, we can also look at a similar increase for state one for comparison reasons. Here, a one standard error increase would imply no changes in the exchange rate. As mentioned, we should not interpret too much from this coefficient due to its statistical insignificance. One reason to this insignificance could be the fact that there are far fewer observations available for state one. There are just over 6 years of observations clearly belonging to state one, while the remaining observations fit state two. This could mean that there is too little variation available in order to estimate a good fitting relationship for state one. However, it could also suggest that the equilibrium exchange rate becomes more dependent on the oil price the shorter its long run solution is based on, further strengthening the conclusion that the oil rice has mostly short-run effects on the exchange rate.

Further, we perform a set of Wald tests in order to test whether or not the effects of $oilp_{t-1}$ and $\Delta oilp_t$ are equal across the two states. In addition, we test whether the total effect of all statistically significant oil price terms is equal across the states. All the null hypotheses are, at least weakly, rejected and we conclude that the effect of the oil price is, in fact, different between the two states.[9] Based on these tests and our estimations, we conclude that the oil price had a greater short-run impact on the exchange rate following the introduction of inflation targeting in Norway in the short run. This could be a consequence of Norges bank intervening more in the first period in order for the exchange rate to remain within its allowed range, while it was more freely floating in the second time period.

Summing up, it seems like the oil price had more to say for the long run equilibrium exchange rate during the managed float regime. Following the introduction of the inflation targeting regime, the equilibrium exchange rate was mostly influenced by the differences in prices, while the oil price had little to say. From this, we can say that there is stronger evidence of PPP holding in the long run under the inflation targeting monetary policy regime than under the managed float regime, and that the oil price has more short-term effects on the exchange rate. This is also suggested by the short run estimations, where $\Delta oilp_t$ is statistically significant only in state two, while its lags are statistically significant in state one. The latter would suggest that changes in the oil price would have more long term effects in state one, while it would have more immediate effects on the exchange rate in state two.

6.3 Oil price and exchange rate non-linearity

As mentioned earlier, there are reasons to believe that changes in the oil price do not have symmetrical effects on the exchange rate. To investigate this, we look at the three specific events mentioned earlier where the oil price rose and fell sharply, before and after the introduction of inflation targeting. We also assume that the exchange rate movements were caused by changes in the oil price, as we find that the oil price predominantly is the only statistically significant variable. This is done to see how much these events affected the exchange rate, and whether or not there is a difference in the exchange rate effect of increments and decrements in the oil price. Following the 1990 spike in oil prices where the oil price rose by 63.7%, the exchange rate

[9] We tested the null hypotheses that $\phi_{01} = \phi_{02}$, $\phi_{11} = \phi_{12}$ and $\phi_{01} + ... + \phi_{21} = \phi_{02} + ... + \phi_{22}$, which yielded p-values of 0.0033, 0.0000 and 0.0870 respectively. Note that ϕ_{3s} is excluded from the last test, as it is insignificant in both states.

depreciated by 1.66% before further depreciating by 0.11% after the reduction back to its pre-shock level. Prior to the GFC, the oil price more than doubled from 57$ to 121$, causing a 2.77% appreciation of the NOK-ECU exchange rate before depreciating by 11.35% in the following oil price reduction back to its pre-GFC levels. In the more recent oil price fall starting in 2014 from an oil price of 108$ to its low point at 37$ in the first quarter of 2016, the exchange rate depreciated by 14.13%. Comparing these events indicates that oil price increases had no appreciating effect in 1990. Rather, there was a depreciation of the exchange rate, but this is most likely be the result of the Krone being fixed to the ECU in this period, counteracting any oil price effects. Further, the appreciating effect of the oil price reduction prior to the GFC is smaller than the depreciating effect of an equal reduction in the oil price during the GFC, indicating that decrements in the oil price have more to say on the exchange rate than increments. This is somewhat backed up by the fall in the oil price from 2014, which resulted in a large depreciation of the exchange rate. To investigate this further, we will in the following section estimate a model where non-linear effects like this are included.

6.3.1 A model with asymmetric oil price effects

Up until this point, we have based our analysis on the assumption of an increase and a decrease of the oil price has symmetric effects on the exchange rate through the use of a log-linear model. One can, however, argue that this assumption is too simple and that the oil price effects are not symmetric. A decrease in the oil price could, as seen above, have larger impacts on the Norwegian economy than an increase. One explanation to this could be through the activity in the oil sector. Following a decrease in the oil price, revenues of Norwegian oil exporters will decrease, and they may find themselves in a position where cutbacks are needed, causing repercussions throughout the rest of the Norwegian economy. This could cause a greater depreciation of the NOK exchange rate than the isolated effect of an reduced oil price, as the market expectations for the Norwegian economy may be worsened. Following an increase in the oil price, however, the opposite repercussions may not be expected. Increased revenues for oil exporters may not imply the same increase in activity as a reduction, and may not increase the market expectations for the Norwegian economy in the same size. Also, a central bank may be more willing to adjust interest rates to contradict an economic recession than when the economy is growing. This could imply that the effects on the exchange rate would be greater following an increase in the oil price than it would be following an decrease in the oil price.

As mentioned, Akram (2002) argued that the use of log-linear models may be the cause of previous literature not finding statistically significant effects of the oil price on the Norwegian exchange rate. Following this train of thought, we also look at the possibility of the oil price having asymmetrical effects on the exchange rate. We do this by altering the (restricted) linear ECM from earlier, splitting $\Delta oilp$ into $\Delta oilp^{+}$ and $\Delta oilp^{-}$, i.e. we have a variable catching up the effect of increasing oil prices, and one catching up the effect of falling oil prices.[10] This is similar to the procedure of authors such as Saskia (2016), which looks at different sources for asymmetric oil price effects on the Norwegian exchange rate from 2001-2015. We do not include lags of either of the variables as the change of the oil price tends to move between positive and negative frequently. Such coefficients would show the effect on the exchange rate at time t from the last time the oil price went up or down, and thus not make much sense to include.[11]

$$\begin{aligned}\Delta e_t = &-\alpha\big(e + cpif - cpi\big)_{t-1} - \Pi\big((RB - RBf)\big)_{t-1} + \delta_0 \Delta e_{t-1} + \delta_1 \Delta e_{t-2} \\ &+ \beta_1 \Delta cpi_{t-1} + \beta_2 \Delta cpif_{t-1} + \beta_3 \Delta RB_{t-} + \beta_4 \Delta RBf_{t-1} + \beta_5 \Delta FYI_{t-1} + \beta_6 \Delta NIBOR_{t-1} \\ &+ \phi_0 oilp_{t-1} + \phi_1 \Delta oilp_t^{+} + \phi_2 \Delta oilp_t^{-} \end{aligned} \tag{6.4}$$

Estimating this relationship by OLS for the three separate time periods, we receive the estimation results in table 6.3 where we suppress the estimated coefficients of the control variables as their effects are similar to those reported earlier.[12]

[10] $\Delta oilp^{+} = \Delta oilp$ if $\Delta oilp > 0$, else $\Delta oilp^{+} = 0$ and $\Delta oilp^{-} = \Delta oilp$ if $\Delta oilp < 0$, else $\Delta oilp^{-} = 0$.

[11] Akram (2002), on the other hand, included a variable catching up the effect of falling oil prices and two variables catching up the effects of changes in the oil price given that the oil price was outside what he defined as its normal range.

[12] A full estimation table including the control variables can be found in the appendix.

Table 6.3: OLS estimations of dynamic non-linear model.

	1&2	1	2
	Δe	Δe	Δe
Δe_{t-1}	0.161*	-0.0635	0.150
	(0.0946)	(0.181)	(0.121)
Δe_{t-2}	0.192**	-0.342*	0.350***
	(0.0918)	(0.169)	(0.123)
$(e + cpif - cpi)_{t-1}$	-0.126**	-0.199	-0.190***
	(0.0488)	(0.124)	(0.0572)
$(RB - RBf)_{t-1}$	0.000664	-0.000432	0.00561
	(0.00212)	(0.00385)	(0.00382)
$oilp_{t-1}$	0.000889	-0.0383**	0.0125
	(0.00280)	(0.0158)	(0.00771)
$\Delta oilp_t^+$	-0.0327	-0.0911**	-0.0137
	(0.0298)	(0.0419)	(0.0417)
$\Delta oilp_t^-$	-0.105***	-0.0339	-0.128***
	(0.0198)	(0.0324)	(0.0247)
_cons	0.258**	0.535*	0.339***
	(0.106)	(0.294)	(0.125)
N	105	41	64

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As earlier, we find the long-run solution of the estimations which, not surprisingly, becomes quite similar to the long-term solution for the restricted linear model. This is due to all asymmetrical effects are short term effects, and thus the solutions are not included here.[13] Concerning the estimated α's, much is similar to that of the linear model. The coefficient is statistically significant for both the whole and second time period, while it is not in the first time period. Although all still are below 20%, the estimated α's for the second time period suggest that 19% of a deviation from the long-run equilibrium is corrected through $(e + cpif - cpi)$ each quarter. This is the largest out of all our estimated and statistically significant α's, resulting in the lowest statistically significant half-life at 3.28 quarters. For the whole period, an estimated α at

[13] The long-run solution can be found in appendix C.1.

-0.126 suggest a half-life of 5.15 quarters. In the first time period, the estimated α is statistically insignificant, but equaling -0.199 it suggests a half-life of 3.12 quarters. Again, this points in the direction of PPP being the driving force behind the equilibrium exchange rate determination during the inflation targeting monetary policy regime, while the evidence of PPP is less clear and indicate that the oil price may have had more to say for the equilibrium exchange rate determination during the managed float time period.

The short-run estimation results are also quite similar to earlier, but we do find some interesting differences in the oil price effects between the periods.[14] In the first period, the coefficient of positive changes in the oil price are statistically significant while negative are not. A 1% positive change will cause a 0.0911% appreciation of Δe_t. In the second time period, the opposite applies. A fall in the oil price has a statistically significant effect, while increments do not. Here a 1% reduction of $\Delta oilp_t$ will cause a 0.128% depreciation of Δe_t. As we have previously done, one could speculate that this is a result of Norges Bank's interventions in the pre-2001 period, where depreciation pressure caused by increasing oil prices was counteracted by Norges Bank, but appreciation pressures may not have been to the same degree. In the second period, it is harder to say why the effects are not symmetrical, except through the oil sector activity as explained above. Another explanation could be that the large drop in oil prices in 2014 affected the estimations of such a magnitude that the coefficient of $\Delta oilp^+$ become insignificant, i.e. that the effects could have been symmetrical in absence of this event. The latter would then also apply for the estimation results for both periods as a whole. Whatever the cause of this asymmetry may be, it is a reassuring result from the Norwegian exporting economy's point of view. When the oil price falls, the Norwegian export economy would benefit from a depreciation. Not only will income from exports increase in terms of NOK, Norwegian exports would become more competitive as it becomes relatively cheaper for our tradings partners which could increase demand for Norwegian goods. An appreciation following an increase in the oil price would have the opposite effects. We thus find evidence of the exchange rate moving in favor of the Norwegian economy when the oil price falls, while it may not move in a disadvantaging direction when the oil price increases.

[14] Note that the coefficient for $oilp^-$ should be interpreted as a depreciation. As decrements in the oil price are negative, the total effects on Δe is $[-\Delta oilp^- \times -\beta_{oilp^-}]$, i.e. positive.

Looking at the statistically significant changes in $\Delta oilp$ by one standard error, we have the following statistically significant estimated effects on the exchange rate. In the whole time period, such a fall in the oil price results in a 0.0170% depreciation of the exchange rate, while an increase in the oil price by one standard error results in a 0.014% appreciation of the exchange rate in the first time period. Lastly, a one standard error decrease in the oil price would results in a 0.021% depreciation of the exchange rate in the second time period. The depreciation following a typical fall in the oil price is larger in the second time period than the appreciation caused by a typical increase in the oil price in the first time period, i.e. typical movements in the oil price had larger effects on the exchange rate after inflation targeting was introduced than before 2001.

To see whether or not the effects of increments and decrements in the oil price are significantly different from each other, we perform Wald tests on the asymmetrical oil price effects. Based on these, we are able to conclude that the oil price effects are statistically significantly different from each other in the whole and second time period. In the first time period, on the other hand, we can not say that the effects are statistical significant different from each other, only that one of the coefficients are significant, while the other is not.[15] We also perform a Chow test on all the estimated coefficients of the explanatory variables being equal between the two time periods and conclude that at least one of the estimated coefficients are statistically significantly different from each other at a 1.7% significance level. In addition, we perform post-estimation tests for heteroscedasticity and autocorrelation using the same procedure as earlier, and the results of these test can be seen in table B.5 in the appendix. Not surprisingly, there are little changes in the conclusion of these tests, and we have evidence of heteroscedasticity in the whole period, but not in the two separate time periods. Based on this, we perform appropriate tests for autocorrelation for each period and clearly can not reject the null hypothesis of no serial correlation in either time period. Due to the evidence of heteroscedasticity in the whole period, we re-estimate this using robust standard errors. However, as earlier, there are no changes in the statistical significance of the coefficients, and our conclusion remains unchanged.

We conclude that decrements in the oil price had more to say on the exchange rate than incre-

[15] The null of $\phi_1 = \phi_2$ is rejected at 8%, 33% and 4% significance level in the whole, first and second time period respectively.

ments in the time period following the introduction of inflation targeting. On the contrary, we have statistically significant effects of increments in the oil price, but can not say that the two effects are statistically significantly different from each other in the managed float time period, i.e. there is less evidence of asymmetrical effects in this time period. It seems like market expectations following a drop in the oil price have more to say when the exchange rate is freely floating than when Norges bank would intervene. To further investigate this issue, we estimate the non-linear relationship using a Markov-switching model as we did with the linear model.

6.3.2 Asymmetrical Markov-Switching

Allowing the oil price effects in the non-linear model (6.4) to vary with which state they belong to, we perform a Markov-switching estimation. The estimation results are presented in table 6.4, where we suppress most of the estimated effects of the non-state dependent variables as there are little to no changes in these and their interpretation compared to what have been presented before. This is also the case regarding the long run solution as there are no notable changes from those presented before, except for there being no statistically significant long-run oil price effects in either state. [16]

Table 6.4: Markov-Switching estimation of the non-linear model

Δe_t				
Δe_{t-1}	0.277***	(0.0789)		
Δe_{t-2}	0.181**	(0.0789)		
$(e+cpif-cpi)_{t-1}$	-0.0986**	(0.0455)		
	State 1		State2	
$oilp_{t-1}$	-0.0554	(0.00477)	0.00400	(0.00397)
$\Delta oilp_t^+$	-0.153***	(0.0455)	0.00899	(0.0283)
$\Delta oilp_t^-$	-0.0115	(0.0267)	-0.148***	(0.0202)
constant	0.219**	(0.0965)	0.186*	(0.100)
σ_1^2	0.0142		σ_2^2	0.0144
p11	$1.99*10^{-7}$		p12	0.999
p21	0.612		p22	0.388

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

[16] The full estimation table can be seen in table B.7 and the long run solution in C.2, both found in the appendix.

The estimated state predictions are not nearly as stable in the estimation as in the Markov-switching estimation of the linear model. Especially $p11$ is quite low and contributes to unstable states. However, the estimations should still be valid, but may not be as precise as the linear one. At $\alpha = 0.0989$, the speed of adjustment coefficient is the lowest of any of our previous estimated α's. As it is statistically significant and negative, we can say that 9.89% of deviation from the long-run equilibrium exchange rate is corrected though the real exchange rate per quarter, resulting in a half-life of deviations by 6.66 quarters. There also seem to be a relatively large dependency of the exchange rate on its previous values, as both the coefficients of Δe_{t-1} and Δe_{t-2} is statistically significant and positive, i.e. shocks may have lasting effects on the exchange rate. Concerning the estimated oil price effects, much is similar to the OLS estimation of the non-linear model. Increasing oil prices have statistically significant effects in state one, and a 1% increase in $\Delta oilp$ has an estimated 0.153% appreciating effect on the exchange rate. In state two, the opposite applies and a reduction in $\Delta oilp$ by 1% has a 0.148% statistically significant depreciating effect on the exchange rate. A one standard error increase in the oil price in state one implies a 0.0242% appreciation of the exchange rate, while a one standard error fall in the oil price in state two implies a 0.0245% depreciation of the exchange rate. Performing Wald tests on whether or not the asymmetrical oil price effects are equal in the two states also clearly reject the null of them being so.[17]

This Markov-switching estimation thus further confirms the estimations from the OLS regression that decrements in the oil price have more to say on the exchange rate than increments when the exchange rate is more volatile, while the opposite applies when it is less volatile. Although we previously have established that the more volatile time period corresponds to the time when inflation targeting was present, the change in the state variance is rather low. Combined with the unstable states, we are careful in interpreting too much from estimated state difference on whether or not falling oil prices had more to say on the exchange rate after inflation targeting was introduced and vice versa. The estimations do, however, point in the same direction as the non-linear OLS regressions, and could strengthen its conclusion. In addition, the long-run solutions point in the same direction of most of our previous long-term solutions; That the equilibrium exchange rate is independent of oil prices and interest rates, but reflects

[17]The tests of $\phi_{11} = \phi_{12}$ and $\phi_{21} = \phi_{22}$ are rejected at p-values of 0.0027 and 0.0001 respectively.

the relative price growth of Norwegian and EU prices, such as the PPP theory implies.

We have now estimated five models showing how the oil price effect increased with the change of monetary policy, and how rising and falling oil prices may have differing effects on the exchange rate. However, how well these perform in predicting actual changes in the exchange rate is not yet covered. In the next section, we do this by modelling the oil price effects in some well-known events and look at how well the prediction power of each model is.

6.4 Comparing the estimated effects of real events between our models

In motivating the use of a non-linear model, we looked at some events where the oil price rose and fell sharply in order to see how the exchange rate reacted. As a final look at our estimated models, we will compare how the model prediction of some events fit with the actual movements of the exchange rate. These include the oil price movements of the GFC and the 2014 fall in the oil price, but also the increase in oil price following the Gulf war and the several factors causing a fall in the oil price from 1996-1999. In order to find this estimated effect on the exchange rate, we calculate the total change in oil price and multiply it with the estimated ϕ's.[18] These estimated effects are summed up in table 6.5, where the first three columns contain actual data and the rest contain estimated effects where the estimated coefficients are statistically significant.[19]

Table 6.5: Comparison of model predictions on changes in the oil price

				Estimated effects on Δe				
Scenario	Δe	$\Delta oilp$	Period / state	Unrestricted linear	Restricted linear	Markov switching	Asymmetrical effects	Asymmetrical Markov-switching
1994-1996	-0.0306	0.523	1&2	-0.0348	-0.042			
			1	-0.0278	-0.0383		-0.0477	-0.0800
1996-1999	0.0573	-0.735	1&2	0.0489	0.0590		0.0772	
			1	0.0390	0.0539			
2007-2008	-0.028	0.743	1&2	-0.049	-0.060			
			2	-0.049	-0.069	-0.068		
2008-2009	0.108	-0.727	1&2	0.048	0.058		0.076	
			2	0.048	0.067	0.066	0.093	0.108
2014-2016	0.132	-1.166	1&2	0.078	0.094		0.122	
			2	0.077	0.108	0.107	0.149	0.173

[18]For example, after 2014 this is calculated as $\Delta oilp_{2014-2016} = oilp_{2016q1} - oilp_{2014q1}$.

[19]Note that the column of actual Δe will slightly differ from those mentioned in section 6.2.1 as they are percentage change in the exchange rate while table 6.5 use changes in logarithms.

The estimated effects give us an indication of how good our estimation corresponds to actual changes, but one should keep in mind that the actual changes may be affected by other factors than the oil price which is not caught up in the estimated ϕ's. However, as the oil price and the real exchange rate are the only variables which continuously has statistically significant effects on the exchange rate in the short run, we expect these ϕ coefficients to play a major part in deciding exchange rate movements.

How well the estimated effects coincide with the actual changes in Δe varies a bit, but all estimated effects are in the expected direction and seem to fit rather well in value with the actual changes in Δe. However, some results are more noteworthy than others. The unrestricted model has more parsimonious estimated oil price effects than the other models in all scenarios, i.e. it suggests that less of the movement in the exchange rate was caused by changes in the oil price. Prior to the introduction of inflation targeting, the linear models estimated effects are closer to the actual movement in the exchange rate than the non-linear model's estimated effects. This could, however, be a result of us not being able to find a statistically significant difference in the effects of falling and rising oil prices in this time period as mentioned before, suggesting that the oil price had more symmetrical effects on the exchange rate under the managed float monetary regime. In the two events where the oil price fell after inflation targeting was introduced, the non-linear estimated effects are closer to the actual movements in the exchange rate than those of the linear model. In the 2007 rise of the oil price, there are no statistically significant effects of the oil price in the non-linear models.

The table thus shows us a nice confirmation of what our previous estimations and tests have indicated. After inflation targeting was introduced, the estimated oil price effect on the exchange rate is larger when oil prices are falling than when rising. In the pre-2001 period, on the other hand, the effects seem to be more symmetrical. In addition, we see that even though the size of the changes in the oil price is not that different from each other in size, their estimated effect on the exchange rate is much larger in the three latter events. This further confirms our conclusion about the oil price having a greater effect on the exchange rate under inflation targeting than under the managed float monetary policy.

7 Conclusion

In this thesis, we have established a relationship between the oil price and the NOK-ECU exchange rate through the use of an equilibrium correction model on data from the first quarter of 1990 to the third quarter of 2016. This time period was chosen as it contains a major event in the Norwegian monetary policy, the official adoption of inflation targeting as a monetary policy officially replacing the managed float monetary policy of the 90's and early 2000's. Following this event, the exchange rate volatility increased drastically, highlighting the second major issue we have looked into; whether or not the effect of the oil price on the exchange rate increased when inflation targeting was introduced.

We derived the ECM through combining two theories of international trade and exchange rate determination, the purchasing power parity and uncovered interest parity conditions. These were both assumed to hold in the long run such that a long-run equilibrium exchange rate exists. Through allowing the effects of the expected exchange rate to be captured by some real factors, the oil price was included in the model. In estimating this theoretical model, a simple OLS regression was used on a linear model, while at the same time, emphasizing the effect of monetary policy on the oil price effect by splitting the time period in two. Based on the lack of statistical significance of some explanatory variables and our expectations of their effects, the linear model was restricted by allowing a range of explanatory variables to only affect the exchange rate through their lagged values. To further investigate the role of monetary policy regime, a Markov-switching estimation approach was applied, allowing for the effect of the oil price to change with the monetary policy regime. Based on evidence of increments and decrements in the oil price affecting the exchange rate differently, we allowed the oil price to have asymmetrical effects on the exchange rate, i.e. that falling oil prices may affect the exchange rate differently than increasing oil prices. Also in this non-linear estimation, we emphasized the role of the monetary policy regime, investigating the time periods separately and allowing for the oil price effect to change with the monetary policy regime through a Markov-switching estimation.

From our empirical results, we find that the oil price does, in fact, have statistically significant effects on the Krone exchange rate. Increased oil prices appreciate the exchange rate while decreased oil prices depreciate the exchange rate, both through the Harrod-Balassa-Samuelson effect. In the linear OLS over the whole time period, this effect is approximately −0.0665% and −0.0803% in the unrestricted and restricted model following a 1% increase in $\Delta oilp_t$. Splitting the time period in two, the equivalent effects are −0.0531% and −0.0658% before and after 2001 in the unrestricted model, while −0.0733% and −0.0926% in the restricted one. We thus find statistically significant evidence that the oil price effect on the exchange rate increased after inflation targeting was introduced in 2001. This makes sense as the central bank may, to a larger degree, intervene in order to limit exchange rate movements under the managed float monetary policy regime present during the 90's than when the central bank follows a inflation targeting monetary policy regime. The Markov-switching estimation of the restricted linear model further backs up this conclusion. Here, the data is split into two different states, one more volatile than the other, and the oil price effect is allowed to change with the states. Comparing the state prediction to actual historical events, the states are near perfect in predicting whether or not the exchange rate was freely floating. It gives us a clear change of states from state one to the more volatile state two towards the end of the 90's when, due to a range of speculative attacks and a statement by Gjedrem in 1999, inflation targeting was de facto introduced. We find a −0.0914% statistical significant effect on the exchange rate following a 1% change in the oil price in state two. In state one, we find no statistically significant effect of $\Delta oilp_t$, but rather a statistically significant effect at −4.2% on the exchange rate following a 1% change in $oilp_{t-1}$. The latter could be a result of state one containing few observations, suggesting that oil price effects are, in fact, short run. Tests are done for all estimations to see whether or not the oil price effects are equal in the two different states and time periods, and the results conclude that the oil price effect did, in fact, change. We also look at one standard deviation increases in oil price in all estimations and find that typical movements in the oil price had larger impacts on the exchange rate after inflation targeting was introduced.

When looking at the estimated effects of some events where the oil price had rapid and large movements such as the GFC, we find evidence of falling oil prices affecting the exchange rate more than increasing oil prices in the post-2001 time period. Performing OLS estimations of a non-linear model where we allow for this asymmetrical effects, we find a 0.128% statistically significant depreciating effect of a 1% oil price fall in the in the second time period. For the first time period, the opposite applies, with an estimated 0.0911% appreciating effect following a 1% increase in the oil price. Allowing oil price effects to change with the monetary policy regime, the Markov-switching estimations of the non-linear model strengthen our conclusions from the OLS estimations. Falling oil prices have a 0.148% statistically significant depreciating effect on the exchange rate in state two while increasing oil prices have a 0.153% statistically significant appreciating effect on the exchange rate in state one. The results could be caused by market expectations affecting the exchange rate more under inflation targeting, and that falling oil prices may decrease the expectations of the Norwegian economy more than rising oil prices increases expectations. Under the managed float regime, on the other hand, the central bank may be more willing to intervene when oil prices are falling in order to maintain exchange rate stability and counteract recessions in the Norwegian economy than intervening against growth when oil prices are rising, i.e. the exchange rate may be allowed to react when oil prices increase but not when they are falling. We do, however, find less evidence of asymmetrical effects in this time period than under inflation targeting, suggesting more symmetrical effects.

We find statistically significant evidence of long run solutions in all models. This follows from cointegration being present due to the estimated α coefficient being negative, statistically significant and/or through Johansen tests for cointegration. However, the oil price and interest rate effect in these long-run solutions has low statistical power, suggesting that the long-run equilibrium exchange rate is mainly decided through the relative price growth in Norway and the EU. This is especially true in the inflation targeting time period, indicating that the equilibrium exchange rate is determined by the purchasing power parity condition. Under the managed float time period, however, the evidence of there existing an equilibrium exchange rate through the PPP condition are less clear and suggest that the oil price may have something to say in the equilibrium exchange rate determination. As the latter time period is somewhat short, this could also point in the direction of what we already have found, that the oil price has more short term effects on the exchange rate. Further, the estimated speed of adjustment coefficient, indicating how much of a deviation from the long-run exchange rate is corrected each quarter through the real exchange rate, is continuously below 20%. Although this may seem low for a rapidly changing variable such as the exchange rate, this is a known problem in other literature performing ECM estimations on the exchange rate and assuming PPP holds. Our half-life estimations lie between 3 and 7 quarters, which is lower than the general consensus of the literature.

Summed up, we find that the oil price has statistically significant linear effects on the exchange rate. An increase in the oil price appreciates the exchange rate, while a decrease depreciates it. Further, this effect increased following the adoption of an inflation targeting monetary regime by the Norwegian central bank in 2001. Allowing for the oil price to have non-linear effects on the exchange rate, we find statistically significant effects of increasing oil prices under the managed float monetary regime, while we find statistically significant effects of falling oil prices under the inflation targeting monetary policy regime. However, the evidence of differing effects of falling and rising oil prices are less clear in the first time period, and points in the direction of more symmetrical oil price effects under a managed float monetary policy than under inflation targeting. These conclusions are further backed up by looking at the prediction power of all our models on some well-known events with rapid movements of the oil price. Non-linear models may fit better under the inflation targeting monetary policy, while linear models seem to fit under the managed float monetary policy regime.

Although our research focuses on how the oil price effect changes with monetary policy in Norway which, at least to our knowledge, have not been looked at by other authors, there is great potential for further work on this issue. Due to data availability, we used quarterly data, but using more frequent data such as daily observations would be interesting. This could improve the estimation power of our models, especially in state one of the linear Markov-stitching model, where the number of observations is quite low. This may also allow more complex Markov-switching estimations. Further, allowing for non-linearity through threshold values such as Akram (2002) did, and looking at how this changed with the monetary policy would be interesting. However, as Ferraro et al. (2015) concludes, allowing for non-linearity does not always improve model predictions against simple linear models. Lastly, looking at the same issue with other assumptions than the PPP and UIP conditions holding in the long run would be interesting.

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A Graphs

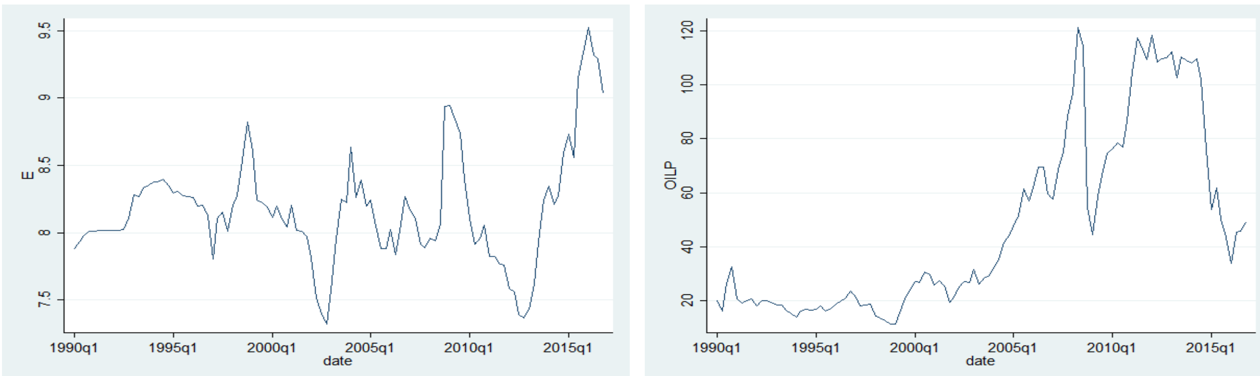

Figure A.1: Nominal NOK-ECU exchange rate (left) and European crude brent oil price in USD (right)

Figure A.2: Bond interest rate difference (left) and NIBOR interest rate (right)

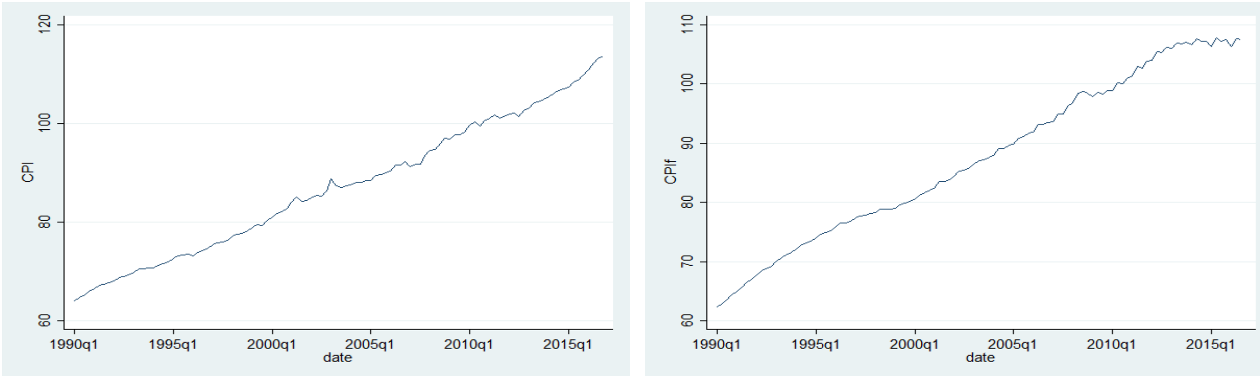

Figure A.3: Consumer price index in Norway (left) and EU19 (right)

Figure A.4: Current account balance relative to GDP (left) and real NOK-ECU exchange rate (right)

B Tables

Table B.1: Augmented Dickey-Fuller test results

Name	Lags	Constant	Trend	TS	p
e	3	yes	no	-3.137**	0.0239
e_{before}	1	yes	no	-2.693*	0.0753
e_{after}	3	yes	no	-1.953	0.3075
RB	3	yes	no	-1.991	0.2906
RBf	2	yes	no	-1.758	0.4014
$RB-RBf$	2	yes	no	-2.304	0.1706
FYI	2	yes	no	-1.974	0.2981
$oilp$	3	yes	no	-1.114	0.7094
cpi	1	yes	yes	-3.213*	0.0819
$cpif$	4	yes	yes	-1.864	0.6730
$e-cpi-cpif$	2	yes	no	-3.305**	0.0147
$NIBOR$	3	yes	no	-2.501	0.1152
Δe_{before}	0	yes	no	-5.941***	0.0000
Δe_{after}	0	yes	no	-6.512***	0.0000
ΔRB	2	yes	no	-5.919***	0.0000
ΔRBf	1	yes	no	-7.037***	0.0000
$\Delta RB-RBf$	1	yes	no	-7.513***	0.0000
ΔFYI	1	yes	no	-4.748***	0.0001
$\Delta oilp$	1	yes	no	-8.475***	0.0000
Δcpi	0	yes	yes	-11.542***	0.0000
$\Delta cpif$	4	yes	yes	-5.836***	0.0000
$\Delta NIBOR$	2	yes	no	-5.147***	0.0000

H0 rejected at 10*, 5** and 1***%.

P-value based on MacKinnon approximate.

	Order of integration
e	I(0)
e_{before}	I(1)
e_{after}	I(1)
RB	I(1)
RBf	I(1)
$RB-RBf$	I(1)
FYI	I(1)
$oilp$	I(1)
cpi	I(1)
$cpif$	I(1)
$e-cpi-cpif$	I(0)
$NIBOR$	I(1)

Table B.2: Johansen test on the number of cointegrated relationships

$e\ oilp\ FYI\ cpi\ cpif\ RB\ RBf\ NIBOR$

Type of test	Lags	Cointegrating rank	Period
Trace	4	1^{***}	1 & 2
Max	4	1^{***}	1 & 2
Information criteria	4	1	1 & 2
Trace	2	3^{***}	1
Max	2	3^{***}	1
Information criteria	2	3	1
Trace	1	1^{***}	2
Max	1	1^{***}	2
Information criteria	1	2	2

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Period 0 corresponds to the time period before 2001q1, and period 1 to 2001q1 and onwards

Table B.3: Durbin's alternative and ARCH test for autocorrelation, and Breusch-Pagan test for heteroscedasticity. Linear restricted and unresticted model.

Period	lags(p)	Durin's alternative χ^2(p)	ARCH χ^2(p)	Breusch-Pagan χ^2(1)
Unrestricted model				
1 & 2	1		0.049	
1 & 2	2		0.914	7.81^{***}
1	1	0.277		
1	2	0.818		0.28
2	1	0.220		
2	2	0.805		0.4841
Restricted model				
1 & 2	1		0.358	
1 & 2	2		0.873	9.00^{***}
1	1	0.118		
1	2	0.964		0.00
2	1	0.361		
2	2	0.550		0.31

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

H_0 : of no autocorrelation at lag p for Durbins alternative and ARCH.

H_0 : of constant variance for Breusch-Pagan.

Table B.4: Full OLS estimation table on non-linear model

Period	1&2	1	2
	Δe	Δe	Δe
Δe_{t-1}	0.161*	-0.0635	0.150
	(0.0946)	(0.181)	(0.121)
Δe_{t-2}	0.192**	-0.342*	0.350***
	(0.0918)	(0.169)	(0.123)
$(e+cpif-cpi)_{t-1}$	-0.126**	-0.199	-0.190***
	(0.0488)	(0.124)	(0.0572)
$(RB-RBf)_{t-1}$	0.000664	-0.000432	0.00561
	(0.00212)	(0.00385)	(0.00382)
ΔFYI_{t-1}	0.0192	0.0525	0.0527
	(0.0694)	(0.125)	(0.0921)
$\Delta NIBOR_{t-1}$	-0.0000252	0.00304	-0.0000668
	(0.00337)	(0.00409)	(0.00724)
Δcpi_{t-1}	0.133	-0.0431	0.154
	(0.343)	(0.785)	(0.387)
$\Delta cpif_{t-1}$	0.489	0.414	0.580
	(0.438)	(1.160)	(0.500)
ΔRB_{t-1}	0.00465	-0.00393	0.000549
	(0.00668)	(0.0111)	(0.00967)
ΔRBf_{t-1}	0.00190	0.00530	0.00383
	(0.00575)	(0.0112)	(0.00722)
$oilp_{t-1}$	0.000889	-0.0383**	0.0125
	(0.00280)	(0.0158)	(0.00771)
$\Delta oilp_t^+$	-0.0327	-0.0911**	-0.0137
	(0.0298)	(0.0419)	(0.0417)
$\Delta oilp_t^-$	-0.105***	-0.0339	-0.128***
	(0.0198)	(0.0324)	(0.0247)
_cons	0.258**	0.535*	0.339***
	(0.106)	(0.294)	(0.125)
N	105	41	64

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B.5: Durbin's alternative and ARCH test for autocorrelation, and Breusch-Pagan test for heteroscedasticity. Non-linear model

Period	lags(p)	Durin's alternative χ^2(p)	ARCH χ^2(p)	Breusch-Pagan χ^2(1)
1 & 2	1		0.262	
1 & 2	2		1.191	16.63***
1	1	0.169		
1	2	1.857		0.09
2	1	0.085		
2	2	0.211		0.60

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

H_0 : of no autocorrelation at lag p for Durbins alternative and ARCH.

H_0 : of constant variance for Breusch-Pagan.

Table B.6: Chow test results for all OLS estimations

Model	k	N-2k	F-value	p-value
Dynamic	20	64	1.96	0.022
Dynamic restricted	14	76	1.73	0.067
Asymmetrical	13	78	1.98	0.017

Table B.7: Full Markov-Swtiching estimation table on the non-linear model

Δe_t				
Δe_{t-1}	0.277***	(0.0789)		
Δe_{t-2}	0.181**	(0.0789)		
$(e + cpif - cpi)_{t-1}$	-0.0986**	(0.0455)		
$(RB - RBf)_{t-1}$	0.00145	(0.00172)		
ΔFYI_{t-1}	-0.00827	(0.0640)		
$\Delta NIBOR_{t-1}$	0.000500*	(0.00289)		
ΔRB_{t-1}	0.0198	(0.00542)		
ΔRBf_{t-1}	0.00381	(0.00481)		
Δcpi_{t-1}	0.0342	(0.357)		
$\Delta cpif_{t-1}$	1,121*	(0.435)		
	State 1		State2	
$oilp_{t-1}$	-0.0554	(0.00477)	0.00400	(0.00397)
$\Delta oilp_t^+$	-0.153***	(0.0455)	0.00899	(0.0283)
$\Delta oilp_t^-$	-0.0115	(0.0267)	-0.148***	(0.0202)
constant	0.219**	(0.0965)	0.186*	(0.100)
σ_1^2	0.0142		σ_2^2	0.0143
p11	$1.99e^{-7}$		p12	0.999
p21	0.612		p22	0.388

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

C Long run solutions

C.1 Long run solution for the non-linear OLS estimations

$$e_{1\&2} = 2.047 + (cpi - cpif) + 0.00527(RB - RBf) + 0.00706oilp$$

$$e_1 = 2.688 + (cpi - cpif) + 0.00217(RB - RBf) - 0.192oilp$$

$$e_2 = 1.784 + (cpi - cpif) + 0.0295(RB - RBf) + 0.0658oilp$$

C.2 Lon run solution for the non-linear Markov-switching estimation

$$e_1 = 2.221 + (cpi - cpif) + 0.0147(RB - RBf) - 0.561oilp$$

$$e_2 = 1.784 + (cpi - cpif) + 0.0147(RB - RBf) + 0.0406oilp$$