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Master Thesis

- What does the yield curve tell us about the exchange rate predictability in Norway? -

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Abstract

This research paper examines if information of the term structure of interest rates can predict exchange rate movements in Norway. We look at the Norwegian kroner relative to the US dollar from a period of August 2001 until February 2014. We construct two models were we use the Nelson-Siegel factors as proxies for exchange rate risk premium to answer our research question. Our results suggest that the slope factor is the most valuable factor when predicting the exchange rates.

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1 INTRODUCTION

Does the term structure of interest rates contain information about the exchange rate movements in Norway? We study this question, as we believe its implications might be of interest for investors´ portfolio strategy and the Norwegian central bank´s monetary policy actions. Predicting the movements in the exchange rate based on the term structure can in fact increase investors´ profitability of their investments and help the central bank forecast a potential forthcoming recession.

Our research paper is based on a study done by Yu-chin Chen and Ping Tsang from 2013. They studied the exchange rate predictability by using the term structure of interest rates for the United Kingdom, Canada, Japan and the United States. Norway is a small, open economy compared to the other countries studied before, and it is very reliant on export of various natural resources. For this reason, we believe that our research may provide different results than previous papers.

Instead of focusing on in-sample forecast, we choose to focus on out-of-sample forecast. This is because we believe our research paper will be more related to reality when predicting the exchange rate. To this end, we extract Nelson-Siegel factors from Norwegian and US yield curves and use them as proxies for exchange rate risk premium. We construct two models that will help us explain these movements. The first one uses relative factors, which is based on the cross-country interest rate differentials between Norway and the US. The second one uses single-country factors for both Norway and the US.

We compare both of the models to a benchmark – the Random Walk model. We use two evaluation methods to compare their forecasting ability; *Root Mean Square Forecast Error* (RMSFE), and *Cumulative Sum of Squared Forecast Error Difference* (CSSED). Our results provide evidence for Nelson-Siegel factors (level, slope, and curvature) to contain valuable information about movements in the exchange rates. Our models predict the excess currency returns from one to three months ahead with the slope factor being the best predicative factor. Chen and Tsang (2013) suggest that there are also other elements involved in the determination of excess currency than just the interest rate differentials. As Nelson-

Siegel factors are known for holding information about future economic activity, our results suggest that the currency risk premium is an important element. Currency risk arises from the change in price of one currency in terms of another. By investing in a foreign country with different currency than the domestic currency, investors will always be exposed to the risk of the changing currency ratio. We also suggest an insightful explanation for the *Uncovered Interest Rate* (UIP) *puzzle*, supporting the study by Chen and Tsang from 2013.

The literature of how exchange rates should be treated is enormous. In our research paper, we have chosen to use the asset price approach. The theory states that nominal exchange rates should be treated as an asset price, because it is influenced by expectations of future elements. It is also consistent with a variety of structural models. Nominal exchange rate is defined as the value of one currency in terms of another currency. The asset price approach links nominal exchange rates to the discounted present value of its expected future fundamentals, such as inflation and output. The Nelson-Siegel factors contain information about future economic activity, and can be interpreted as the market participants´ expectations about future fundamentals. When the market experiences turbulence, such as in the recent global financial crisis, investors require higher returns as a compensation for holding riskier assets or bonds. This will then result in higher short-term interest rates, which is captured by the Nelson-Siegel factors. These changes will have an effect on the currency, and hence, currency risk premium. We have therefore decided to use this approximation.

The Nelson-Siegel representation has several advantages. Its flexibility makes it easy to adapt to changes in the yield curve shapes, and it is highly effective on describing dynamics of the yield curve over time, among others.

The exchange rate is one of the most important prices, which is determined in the foreign exchange market. Over the last decades, the importance of the foreign exchange market has grown. A combination of increased international trade and deregulation of financial markets in big economies has led to tremendous growth in the foreign exchange market in just a short period of time. In April 2007, the average of total value of global foreign exchange trading was $3.3 trillion a day

(BIS, 2013). By April 2013, it had reach a number of $5.3 trillion a day. Increased financial and economic interconnectedness has influenced Norway's small and open economy. The exchange rate is an essential source for economic development, which affects the economy in various ways, such as the demand after Norwegian goods and services, financial investments, and domestic inflation (Bernhardsen & Røisland, 2000).

According to the Economic Complexity Index 2013 (ECI) Norway was the 24th most complex economy in the world, and 32nd largest (Macro Connections, 2013). As Norway is reliant on export of its natural resources (mainly oil, gas and fish) to the international market, the natural resources plays an essential role on the trade balance, and are significant to the monetary policy and financial stability. Considering the oil and gas sectors alone, they constitute for approximately 25% of GDP in Norway (Olsen, 2015). The oil sector accounts for 34% of total exports, while the gas sector represents 25% (Macro Connections, 2013).

Studies show that a higher oil price benefit oil-producing economies, resulting in increased welfare, and the degree of the increased wealth depends on the economy´s dependence of the oil and its share (Krugman, 1983; Killian & Park, 2009; Bodenstein, Erceg, & Guerrieri, 2011). For a small, open oil-exporting economy, the exchange rates reflect the fluctuations in the oil price (Ferraro, Rogoff, & Rossi, 2012). Despite the role of the oil price on exchange rate movements, several studies have proven its weakness for predicting the exchange rates. Chen, Rogoff and Rossi´s study (2008) reveals that the exchange rate helps predict the world commodity price index better than a Random Walk, but the world commodity price index does not have any predicative power to explain exchange rate movements. This is consistent with research of Meese and Rogoff (1983) where they found that no fundamentals, including commodity prices, can forecast patterns in the exchange rates better than a Random Walk. We will therefore not include commodity prices or oil prices, in our models.

The link between the exchange rate and interest rate are important factors in the development of the economy, such as the inflation, output, import and export (Sánchez, 2005). Our study will focus on the information contained in the term structure of interest rates to explain the predictability of the exchange rate. There has been done a lot of research within the field of exchange rate predictability for certain important leading economies, but no one has done research of our topic for the Norwegian economy. It is an interesting research question that will help us understand the dynamics between the interest rates and exchange rate movements in Norway.

Our research paper has the following structure: section 2 presents the theoretical framework that we base our research on; while section 3 covers the literature review on previous studies about the information contained in the factors. In section 4, we present the Nelson-Siegel representation, and in section 5 we will describe the data we are using. Moving over to section 6, we explain the empirical framework where we focus on two forecast evaluation statistics. We will then present our empirical results in section 7. Next, we discuss and compare our results with the results from Chen and Tsang in section 8, and in section 9 we have concluding remarks. References we have used are in section 10, and all of our models are in section 11.

2 THEORETICAL FRAMEWORK

In this section we present the basis for our research paper. We present the different theories that is essential for our study and try to explain the mechanism behind the link between the term structure of interest rates and the exchange rates.

2.1 Term Structure of Interest Rates

The concept of the term structure of interest rates is essential in economics, and the first building block in our research paper. It is interesting for economists for several reasons. Firstly, since the actual term structure of interest rates is easy to observe, the accuracy of the predictions of different term structure theories is quite easy to evaluate. Secondly, it provides useful information about how changes in short-term interest rates affect levels of long-term interest rates. Thirdly, it contains valuable information about expectations of agents in financial markets. Term structure of interest rates is defined as the relationship between bond yields and their time to maturity, and is often called the yield curve. The yield curve is a graphical illustration of a plot of yield to maturity (YTM) of zero-coupon bonds and their corresponding time to maturity, predominantly Treasury bonds (Moorad, 2011). It reflects the market´s expectations of future interest rates given the present state of the market, and is therefore the linkage between short- and long-term interest rates (Bodie, Kane, & Marcus, 2011; Campbell, 1995; Campbell & Shiller, 1991). Hence, the yield curve is essential for the valuation of a bond, as well as a valuable tool for financial investors.

YTM can be viewed as the interest rate on the default-free bond that equates the present price to the value of the discounted cash flows - either coupon or payment- on the bond. We can find the yield (*YTM*) of a *m*-period zero-coupon bond at time *t* as follows:

$$B_{m,t} = \frac{\$\,1}{(1+YTM_{m,t})^m} \tag{2.1}$$

Where $B_{m,t}$ is the price of the bond with a face value of \$1.

Campbell (1995) argues that working with continuously compounded yield to maturity (the log) is more convenient. We will therefore take the logs of **Equation (2.1)** to get the yield in log form:

$$ytm_{m,t} = -\frac{1}{m} \log (b_{m,t}) \qquad (2.2)$$

Where $b_{m,t} \equiv \log (B_{m,t})$ is the log bond price and $ytm_{m,t} \equiv log(1 + YTM_{m,t})$ is the continuously compounded bond yield.

2.2 Expectations Hypothesis

For several decades, researchers have been studying the term structure of interest rates and there are many theories explaining the shape of the yield curve. We will go through the traditional theory of the expectations hypothesis.

The expectations hypothesis is a well-known theory of the term structure of the interest rates on default-free securities. As it is one of the most studied theories in financial economics, there are various versions of the expectations hypothesis (Longstaff, 2000; Bekaert et. al., 1997). The main concept of the theory is that variation in long-term interest rates are explained by the movement in expected future short-term interest rates (Bodie et. al., 2011; Campbell & Shiller, 1991; Cochrane & Piazzesi, 2009; Goodfriend, 1998). The spread between yields on the short bonds and long bonds, called the term premium, are assumed to be constant and non-dependent on time. We will explain the expectations hypothesis in further detail based on a paper by Cochrane and Piazzesi (2009). They present three ways of capturing the yield curve relationships:

1. The one month forward rate $F_{m,t}$ is equal to the expected future spot rate:

$$F_{m,t} = \mathbb{E}_t\left[i_{1,t+m}\right] (+\Omega) \qquad (2.3)$$

Where Ω is the forward risk premium. Risk-neutral investors can either choose to a buy forward contract or wait and lend/borrow money at the current spot rate i_{t+m} until the expected returns are equalized. If the investors are not risk-neutral then they will expose themselves to risk, and therefore require a risk premium.

2. The m-period yield equals the average of the expected one-period yields:

$$i_{m,t} = \frac{1}{m}\sum \mathbb{E}_t\left[i_{1,t} + i_{1,t+1} + \cdots + i_{1,t+m-1}\right](+\Omega) \qquad (2.4)$$

   Where Ω is the yield-curve risk premium. This equation says that holding a m-period bond shall yield the same expected return as rolling over one-year bonds.

3. The expected holding period return (HPR) are equal for all bonds of all maturities:

$$\mathbb{E}_t\left[HPR_{m,t+1}\right] = i_{1,t}\ (+\Omega) \qquad (2.5)$$

   Where $HPR_{m,t+1} = \frac{b_{m-1,t+1}}{b_{m,t}} - 1$ is the gain or loss we achieve when buying a m-period bond at time t and selling a $(m-1)$-period bond at time $t+1$, and Ω is the return risk premium.

In their research paper, Cochrane and Piazzesi (2009) state that the three equations are equivalent, implying that if **Equation (2.3)** holds with a zero or constant risk premium then **Equations (2.4)** and **(2.5)** will hold with the same risk premium characteristics over time. The expectations hypothesis infers that when holding long-term bonds over short-term bonds, the risk premium does not change. However, several empirical studies reveal frequent rejections of the expectations hypothesis. Fisher (2001) explains that:

"*The reason the expectations hypothesis fails is not that expectations do not matter; rather it fails because it says that nothing else matters*"

Factors for determining the shape of the yield curve, such as its form and the time-varying risk premium are not taken into consideration by the hypothesis. Therefore, the expectations hypothesis is not a good tool when examining the shape of the yield curve (Engle et. al., 1987; Fisher, 2001). The rejection of the hypothesis suggests that the yield curve reflects something about future economic activity, such as inflation and output growth that can be used as an instrument for the central bank when conducting monetary policy (Ang et. al., 2006; Goodfriend, 1998). An upward sloping yield curve for long-term bonds reflects the expectations of higher future inflation (Mishkin, 1990; Browne & Manasse, 1989; Bodie et. al., 2011). This may result to a future contraction of monetary policy. In order to avoid any extreme counter-inflationary actions afterwards, the central bank can increase the short-term interest rates.

The empirical findings of rejecting the expectations hypothesis may be interpreted as the forward rate being a biased predictor of future spot rate and evidence of time-varying risk premium. In the following section, we will examine this further.

2.3 Uncovered Interest Rate Parity

The *Uncovered Interest Rate Parity* (UIP) theory is one of the most essential foundations of international finance, and an important exchange rate determination theory. It is also the second building block in our paper.

We let i_t be the interest rate on bonds in home currency at time *t*, and $i^*{}_t$ be the interest rate on foreign-currency bond. The UIP holds when:

$$1 + i_t = (1 + i^*{}_t)\mathbb{E}_t \left\{\frac{S_{t+1}}{S_t}\right\} \qquad (2.6)$$

Where S_t *and* S_{t+1} is the nominal exchange rate in period t and $t + 1$, respectively. The nominal exchange rate is defined as the price of foreign currency in terms of home currency. In a world with certainty, the UIP must hold by a simple arbitrage argument. For instance, a Norwegian investor can take one unit of NOK and buy $1/S_t$ units of US bonds that each pay principal and interest $1 + i^*{}_t$. This sum can then be converted back to NOK at date $t + 1$, exchange rate S_{t+1}. The gross home-currency (NOK) must be equal to gross return $1 + i_t$. By writing the UIP in log form, we introduce an approximation under uncertainty:

$$i_t = i^*{}_t + \mathbb{E}_t s_{t+1} - s_t \qquad (2.7)$$

Where the logs of S_t and S_{t+1}, are s_{t+1} and s_t, respectively. The reason behind this approximation is the Jensen´s inequality, which implies a strictly concave log function of the following equation $log\mathbb{E}_t\{S_{t+1}\} > \mathbb{E}_t\{logS_{t+1}\}$. Assuming that UIP holds, a high-yield currency must on average depreciate. This makes sense because high yield currencies are more attractive to foreign investors than low yield currencies. As the demand of high yield currencies increases, so does its price, and hence, it will appreciate. We have the opposite intuition for the low yield currency. Empirical findings reveal that high-yield currencies rather tends to appreciate, which provide support for violation of the UIP. Deviations from UIP indicate that there may exist a currency risk premium.

Our research paper aims to answer if the yield curve can tell us something about the exchange rate predictability in Norway. In order to answer this question, we try to identify the currency risk premium. In the paper by Chen and Tsang from 2013, they define the foreign excess currency returns as the cross-country yields differentials plus percentage appreciation of foreign currency:

$$rx_{t+m} = (i^*_{t,m} - i_{t,m}) + \Delta s_{t+m} \qquad (2.8)$$

Excess currency return for foreign currency captures the risk premium. Investors that tolerate extra risk will have a form of compensation equal to the risk premium. Under the assumption of risk neutral agents and rational expectations, the efficient market condition supports the UIP, implying that cross-country interest rate differentials equal expected exchange rate changes over the same horizon, as shown in **Equation (2.7).** As mentioned earlier in the paper, empirical studies reveal violation of this condition, which also is consistent with our data. Deviations from UIP reflect the presence of time-varying risk premiums and systematic expectation errors ($\bar{\varepsilon}_{t+m}$):

$$rx_{t+m} = (i^*_{t,m} - i_{t,m}) + \Delta s_{t+m} = \rho^F_{t+m} + \bar{\varepsilon}_{t+m} \qquad (2.9)$$

Where the expectation errors are white noise under rational expectations. By assuming rational expectations, the ρ^F_{t+m} will now differentiate the risk premium from expectation errors.

2.4 The Forward Foreign-Exchange Premium

The forward premium puzzle is closely related to the failure of the UIP. In the forward premium puzzle, currencies that are expected to depreciate, in fact tend to appreciate.

Central in the finding of a forward premium puzzle is the failure of the unbiased forward rate hypothesis; which implies that in equilibrium, the forward rate is equal to the expected value of future spot rate.

In other words, the forward rate is an unbiased estimate of the future spot rate:

$$\mathcal{F}_t = E_t\{S_{t+1}\} \tag{2.10}$$

One implication of **Equation (2.10)** is the indication of the expected US dollar profits to be zero, but not necessarily the expected NOK profits. The reason for this is because:

$$\mathbb{E}_t\left\{\frac{1}{S_{t+1}}\right\} > \frac{1}{\mathbb{E}_t\{S_{t+1}\}} \tag{2.11}$$

Which follows from the Jensen´s inequality that says $1/_{(\circ)}$ is a convex function. So, if **Equation (2.11)** holds, we can not simultaneously have that:

$$\frac{1}{\mathcal{F}_t} = \mathbb{E}_t\left\{\frac{1}{S_{t+1}}\right\} \tag{2.12}$$

Which states that the NOK-USD forward rate equals the expected NOK-USD exchange rate. The Siegel´s Paradox (Obstfeld and Rogoff, 2012) implies this phenomenon. The paradox infers that there is no equilibrium in the market if risk-neutral Norwegian investors only care about NOK returns and risk-neutral US investors only care about dollar returns. In other words, for them to meet at equilibrium there must exist a risk premium. Therefore, the wedge created between the forward rate and expected future spot rate ($\mathrm{f}_t - s_t$) is the forward premium. The exchange rate changes can be written as a function of the forward premium:

$$\mathrm{s}_{t+1} - \mathrm{s}_t = a_0 + a_1(\mathrm{f}_t - \mathrm{s}_t) + \epsilon_t \tag{2.13}$$

The simple hypothesis $f_t = E_t[s_{t+1}]$ has been subject to an enormous amount of empirical testing, where s_{t+1} is the log of the spot price of foreign currency at time $t + 1$ and f_t is the log of the forward exchange rate at time t. We test if we can reject the null hypothesis a_0 = 0, a_1 = 1.

Many researchers suggest that the log forward rate is *not* equal to the expected value of the future log spot rate, at least for cross-exchange rates between major countries' currencies (Hodrick 1987). The finding that the forward rates are biased predictors indicates that there is a risk premium on one country's currency relative to another. This means that one can make predictable profits by betting against the forward rate (Obstfeld and Rogoff 1996, 586-591).

The puzzle has served as a theoretical foundation for earning excess returns from the currency speculation known as carry trade. Carry trade is one of the oldest and most popular currency speculation strategies, and consists of borrowing low-interest-rate currencies and lending high-interest-rate currencies (Rebelo, 2011). This speculation strategy is profitable as long as there is a difference between the forward and spot rates, which is equivalent to the failure of UIP. According to UIP, no excess return from such speculation should be possible.

Fama (1984) offers an informative interpretation of the problem. He shows that a small positive or negative slope coefficient (a_1) implies that the rational expectations risk premium on foreign exchange must be extremely variable. If the coefficient (a_1) is estimated below 0,5 in a large sample, then the risk premium must be more variable than the expected change in the exchange rate. This implies that the risk premium is very important to explain the development of the exchange rate (Obstfeld and Rogoff 1996, 586-591). Because of this result, we will examine if the expectations, as captured in the yield curve factors, affect currency risk premium.

3 LITERATURE REVIEW

Researchers have found that shifts or changes in the shape of the yield curve are attributable to three unobservable factors; “level”, “slope” and “curvature”. There is comprehensive macro-finance literature that links these three factors to future economic activity.

Several researchers state that the level factor captures expected long-run inflation. Mishkin (1990) shows that the yield curve predicts inflation and that movements in the longer end of the yield curve are mainly explained by changes in expected inflation. Barr and Campbell (1997) show that long-term expected inflation explains almost 80 % of the movements in long yields. Rudebusch and Wu (2007, 2008) state that the level factor incorporates long-term inflation expectation. They show that when agents perceive an increase in the long-run inflation target, the level factor will rise and the whole yield curve will shift up.

Estrella and Mishkin (1998) show that the term spread (slope factor) is correlated with the probability of a recession. Hamilton and Kim (2002) find that the term spread can forecast GDP growth. Rudebusch and Wu (2007, 2008) find that the slope factor captures the central bank’s dual mandate of stabilizing the real economy and keeping inflation close to its target. When the central bank tightens its monetary policy, the slope factor rises, forecasting lower growth in the future.

As earlier research show, the factors are important to understand future economic activity. The level factor captures expected long-run inflation and the slope factor forecast GDP growth, recession and monetary policy, among others. The literature does not provide a clear interpretation of the curvature factor. The three factors together are important to summarize the expectation information contained in the yield curve.

We will use the method of Chen and Tsang (2013) - where they examined if the expectations, as captured in the yield curve factors, affect currency risk premium. Chen and Tsang (2013) used monthly data from August 1985 to July 2005 for the United States, Canada, Japan and the United Kingdom. They used Fama-Bliss zero-coupon yield data and fitted the three Nelson-Siegel factors to yield curve differences between the three countries and the United States at maturities ranging from 3 months to 10 years.

Cheng and Tsang (2013) discovered that all the three relative yield curve factors (level, slope and curvature) can help predict exchange rate movements and explain excess currency returns 1 month to 2 years ahead. Their results showed that the slope factor was the most robust factor across currencies. In addition, their results offer an intuitive explanation to the UIP puzzle.

Cheng and Tsang's (2013) approach is consistent with previous research using the term structure of the exchange rate forward premiums or the relative yield spread to predict future spot exchange rates, such as Clarida and Taylor (1997), Frankel (1979), and Clarida et al (2003).

4 NELSON-SIEGEL FACTORS

Empirical studies reveal that more than 99 % of the movements in Treasury bond yields are captured by three factors; "level", "slope" and "curvature".

We use a simple, but popular term structure model introduced by Nelson and Siegel (1987). This model is a parsimonious model for yield curves that has the ability to represent the shapes generally associated with yield curves: monotonic, humped, and S shaped. We will extract three Nelson-Siegel (1987) factors – level, slope and curvature – to summarize the expectation information contained in the yield curve.

The Nelson-Siegel curve:

$$i_{m,t} = \beta_{1t} + \beta_{2t}\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + \beta_{3t}\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) \quad (4.1)$$

The three factors have different loadings, which mean that they have a different impact response to the yield curve. The factor loadings show the impact response from a one-percentage point increase in level, slope or curvature on the yield curve for a given maturity.

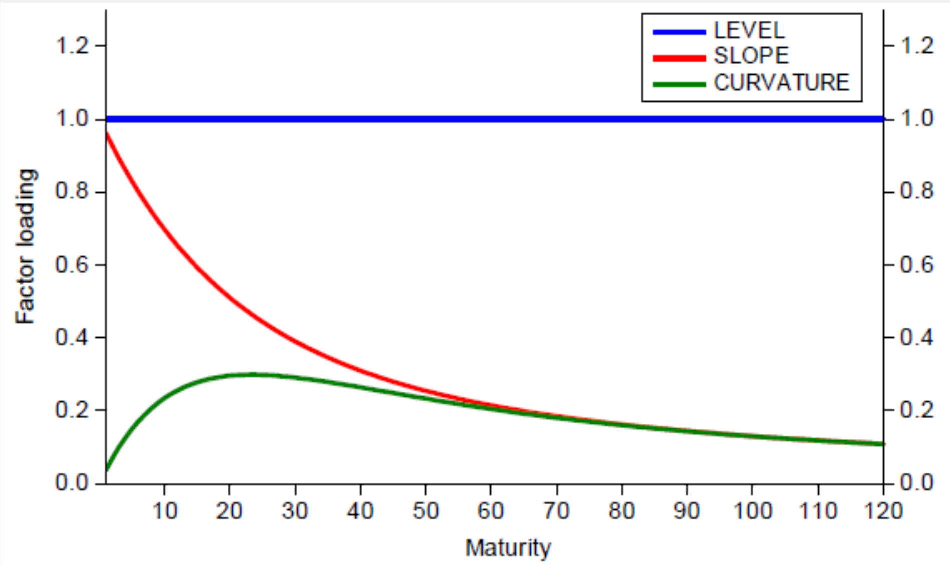

Figure 4.1: *The figure shows the factor loadings from the Nelson-Siegel model.*

The loading on β_{1t} is one, for all maturities (**Figure 4.1**), and may be viewed as the long-term factor. This factor may also be interpreted as the level factor, since the long-term factor governs the yield curve level. An increase in β_{1t} (level shock) increases all yields equally, as the loading is identical at all maturities, thereby inducing a parallel shift that changes the level for the whole yield curve (**Figure 4.2 A**). As mentioned in section 3, there is extensive macro-finance literature that links the Nelson-Siegel factors to future economic activity. For example, several researchers state that the level factor captures expected long-run inflation. This means that if the yield curve shifts up one level, the expected long-run inflation gets higher.

The loading on β_{2t} starts out at one, but decays monotonically and quickly to zero (**Figure 4.1**). This factor may be viewed as a short-term factor. This short-term factor may also be interpreted as the slope factor. An increase in β_{2t} (slope shock) increases short-term yields substantially, but leaves long-term yields unchanged, thereby the yield curve becomes less steep and its slope decreases (**Figure 4.2 B**) Several researchers argue that the slope factor forecast GDP growth, recession and monetary policy, among others. For example, if the yield curve gets flatter it reflects expected GDP slow down.

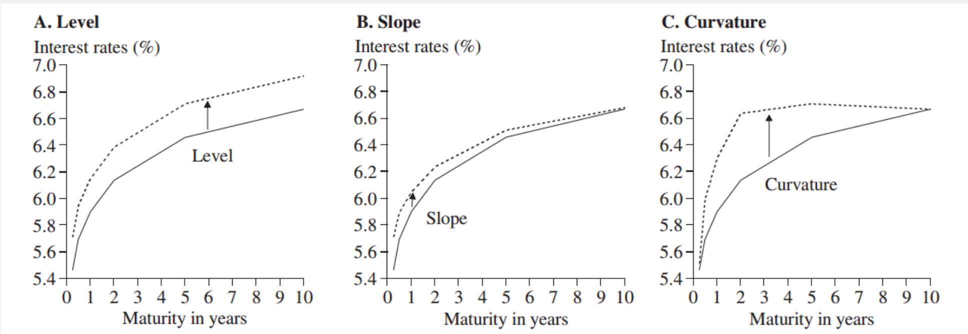

***Figure 4.2**: The figure shows how the three factors – level, slope and curvature - affect the yield curve.*

The loading on β_{3t} starts out at zero, increases, and then decays to zero (**Figure 4.2**). This factor may be viewed as a medium-term factor. This medium-term factor is closely related to the yield curve curvature. An increase in β_{3t} (curvature shock) will have very little effect in very short or very long yields, but it will increase medium-term yields, thereby the yield curve becomes more "hump-shaped" than before (**Figure 4.2 C**).

The lambda parameter (λ) determines the rate of decay on the loadings of S_t and governs where the loading of C_t achieves its maximum. Large values of λ produce fast decay and can better fit the curve at short maturities, while small values of λ produce slow decay and can better fit the curve at long maturities. In our model we have chosen λ=0.0609, as is standard in the literature (Diebold and Li 2006).

The Nelson-Siegel representation has some very appealing features and has several advantages over the conventional no-arbitrage factor yield curve models. First, it is flexible enough to adapt the changing shapes of the yield curve. Second, the Nelson-Siegel form provides a parsimonious approximation and is easy to estimate. Our goal is to relate the evolution of the yield curve to movements in the expected exchange rate fundamentals. Therefore, it is important to us that the Nelson-Siegel representation is one of the best models in describing the dynamics of the yield curve over time. For this reason, the Nelson-Siegel has become very popular for static curve fittings in practice. The Board of Governors of the U.S Federal Reserve System fits and publishes on the Web daily yield curves in real time, as does the European Central Bank (Diebold and Rudebush 2013, 21-25).

5 DATA

We will use interest rates based on *Norwegian Interbank Offered Rate* (NIBOR) to construct the Norwegian yield curve and zero-coupon yield data to construct the U.S. yield curve. NIBOR is the interbank rate in Norway and is the average of interest rates published by six panel banks. It indicates the lending rate of Norwegian kroner to banks that are operating in the Norwegian money market and the foreign exchange market. The rates we use for our research paper might be viewed as incomparable. However, the reason we use NIBOR is (i) because Norway have very few government bonds, and (ii) NIBOR is very often considered as the markets risk free rate.

The data is collected start-of-month from August 2001 until February 2014, for a total of 151 observations. For the Norwegian yields, we will use data from the fourth day of each month. For the U.S yields and the exchange rate we will do the same, however some of the data were not available on this date. For this reason, we used the first available date before the fourth. Even though the dates corresponding to the yields differ, this will not have any effect for our analysis. We will obtain the data from Norges Bank and the Board of Governors of the Federal Reserve System.

The sample period is selected to increase the probability that our data are from a stable period of monetary policy behaviour. The period between December 1992 and March 2001 was a time of transition of monetary policy in Norway. Over that period, the Norwegian authorities moved away from a fixed exchange rate regime, and replaced it with an inflation-targeting regime (Kleivset 2012, Gjedrem 2001). For this reason, we will use data from August 2001, after the inflation-targeting regime was official.

Now we will present descriptive statistics for monthly yields for both the Norwegian and U.S data.

TABLE 5.1 - DESCRIPTIVE STATISTICS NORWAY

Maturity (months)	Mean	Std. Dev	Minimum	Maximum
1	3,54	1,97	1,53	8,51
3	3,63	1,92	1,63	7,86
6	3,71	1,84	1,72	7,90
12	3,67	1,79	1,63	7,70
36	4,07	1,43	1,92	7,44
60	4,33	1,24	2,23	7,25
120	4,73	1,02	2,97	7,18

TABLE 5.2 - DESCRIPTIVE STATISTICS U.S

Maturity (months)	Mean	Std. Dev	Minimum	Maximum
1	1,52	1,68	0,01	5,23
3	2,07	1,70	0,01	5,14
6	1,67	1,72	0,03	5,31
12	1,78	1,67	0,09	5,26
36	2,30	1,49	0,31	5,14
60	2,85	1,33	0,62	5,11
120	3,67	1,01	1,53	5,28

In **Table 5.1** and **Table 5.2** we present the descriptive statistics for the Norwegian and the U.S. yields, respectively. In the U.S. the mean of the yields is increasing with maturity, which indicates that the yield curve is upward sloping and have a positive yield spread (Campbell 1995). We experience the same result for the Norwegian yields, except from the 12-month yield as we see form **Table 5.1**.

The standard deviation is decreasing with maturity; i.e. long rates are less volatile than short rates. This is the case for both the Norwegian and the U.S yields. This is as expected since long yields are risk-adjusted averages of expected short rates (Rudebusch and Wu 2008). Since bonds of shorter maturity have shorter time to correct for shocks in the economy than bonds of longer maturity, we expect to experience more movements in the short yields in response to a shock.

Now we will present the correlation matrices, which describe how the interest rates are correlated across maturities.

TABLE 5.3 - CORRELATION MATRIX NORWAY							
Maturity (months)	1	3	6	12	36	60	120
1	1						
3	0,995	1					
6	0,985	0,995	1				
12	0,971	0,977	0,985	1			
36	0,920	0,921	0,930	0,967	1		
60	0,889	0,885	0,887	0,928	0,989	1	
120	0,838	0,828	0,822	0,861	0,947	0,982	1

TABLE 5.4 - CORRELATION MATRIX U.S							
Maturity (months)	1	3	6	12	36	60	120
1	1						
3	0,998	1					
6	0,994	0,998	1				
12	0,987	0,993	0,997	1			
36	0,925	0,933	0,941	0,962	1		
60	0,852	0,859	0,868	0,897	0,980	1	
120	0,723	0,728	0,737	0,774	0,904	0,970	1

We see that yields of similar maturity are highly correlated. This is the case for both the Norwegian and the U.S yields. This observation implies that there are some common factors that affect the movements of the yield curve, which is consistent with standard stylized facts.

6 EMPIRICAL FRAMEWORK

In this section, we will explain the econometric methodology that we use in our out-of-sample forecasts. Thereafter we will explain the two methods we used when we evaluated our forecasts.

6.1 Rolling Window

A crucial issue in forecasting is parameter instability. To handle this issue, we use only the most recent observations in our forecasts rather than all available observations. This is called a rolling window estimation method. Using this method one produces a sequence of out-of-sample forecasts using a fixed number of the most recent data at each point of time (Rossi 2014). Our goal is to forecast exchange rate returns between time t and $t+m$, using information up to time t.

In addition, we need to take into account how many recent observations should be used in the estimation, i.e. the size of the window. We have chosen the optimal window size that minimizes the conditional *Root Mean Square Forecast Error* (RMSFE), which we will explain in detail in the next section. We use *Ordinary Least Squares* (OLS) to estimate coefficients of the model using 36 observations in a rolling window scheme.

6.2 Out-of-Sample Forecast Comparisons

In order to evaluate the out-of-sample forecast performance of the models relative to the benchmark, we calculate two forecast evaluation statistics. The first statistic is the Root Mean Square Forecast Error of the alternative models relative to that of the benchmark. The second statistic is the Cumulative Sum of Squared Forecast Error Difference. The first evaluation statistic evaluates the overall forecast performance, while the second evaluates the forecast performance over time.

6.2.1 Root Mean Square Forecast Error

Root Mean Square Forecast Error (RMSFE) is by far the most commonly used evaluation method for forecast accuracy. This method measures the difference between values predicted by a model (forecasts) and the values actually observed from the environment that is being modelled. RMSFE is a symmetric loss function, which means that too high or too low forecasts is equally weighted. Smaller forecast errors are considered as better than larger ones, so a low RMSFE value indicates better forecasting performance (Bjørnland and Thorsrud 2015).

$$\text{RMSFE} = \sqrt{\sum \mathrm{E}[(y_{T+m} - \hat{y}_{T+m})^2]} = \sqrt{\sum \mathrm{E}[(e_{T+m})^2]} \qquad (6.1)$$

We will use this measure in two ways. First, when choosing a benchmark model we will use the model with the smallest RMSFE. Second, when evaluating the alternative models, we will use the RMSFE of the alternative models relative to the RMSFE of the benchmark model.

6.2.2 Out-of-Sample Forecast Comparison

In the previous section we looked at the RMSFE, which measures overall forecast performance. In this section, we will now consider the models forecast performance over time relative to the Random Walk model. In order to do this analysis, we will look at a second forecast evaluation statistic. The *Cumulative Sum of Squared Forecast Error Difference* (CSSED) presented by Welch and Goyal (2008):

$$CSSED_{m,\tau} = \sum_{\tau=R}^{T} (\hat{e}_{bm,\tau}^2 - \hat{e}_{m,\tau}^2) \qquad (6.2)$$

Where $\hat{e}_{bm,\tau}$ is the forecast error of the benchmark model (the Random Walk model), and $\hat{e}_{m,\tau}$ is the forecast error of the alternative model. The start of the forecasting period is denoted by parameter R, while the end of the period is denoted by parameter T. When there is an increase in CSSED it will imply that the alternative model outperforms the benchmark model, and we have the opposite interpretation when there is a decrease in CSSED.

We will go more in-depth at these forecasting evaluation statistics in the next section.

7 EMPIRICAL RESULTS

By using the framework in section 6, we will now present our empirical results of the out-of-sample forecast performance for our two main models – Relative-Factors model and Six-Factors model. In the Relative-Factors model, we extract the three Nelson Siegel factors, level, slope and curvature, based on the interest differentials between Norway and the US. In the second model, we extract six Nelson Siegel factors, three for Norway and three for the US.

In this section, we will first present how we chose the benchmark model that we used when evaluating the alternative models. Second, we will discuss the overall forecast performance of the different models by comparing the relative RMSFE. Lastly, we analyse the performance over time by observing the movements of the CSSED.

7.1 Benchmark Model

In order to evaluate our forecast models, we need to choose a benchmark model. To choose a benchmark we perform two analyses to test whether UIP could outperform a Random Walk with and without drift. The Random Walk is defined as a time series process that only depends on past values of itself (Bjørnland and Thorsrund 2015). This implies that the best forecast of $\hat{s}_{t+1}$is $\hat{s}_t$. In the Random Walk with drift, we have added a constant term $\hat{\delta}_{t,m}$to the Random Walk. We will use rolling window, as explained above, to do the forecasts. We will use the best method, the one with the smallest RMSFE, as a benchmark in our analysis.

In the first analysis, we test if the UIP can outperform a Random Walk with drift.

Random Walk w/drift: $$\Delta^m \hat{s}_{t+m|t} = \hat{\delta}_{t,m} \quad (7.1)$$

UIP: $$\Delta^m \hat{s}_{t+m|t} = \hat{\alpha}_{m,t} + \hat{\beta}_{m,t}(i_t^m - i_t^{m*}) \quad (7.2)$$

Where $\Delta^m \hat{s}_{t+m|t}$ is the change in the exchange rate and $\hat{\delta}_{t,m}$ is the drift term. When we test UIP against Random Walk with drift we need to add a constant term $\hat{\alpha}_{m,t}$ in addition to the intercept $\hat{\beta}_{m,t}$. Furthermore, i_t^m is the domestic interest rate and i_t^{m*} is the foreign interest rate.

TABLE 7.1 - RMSFE

	UIP	Random Walk
1 month	0,0356	0,0357
3 months	0,0642	0,0670
6 months	0,0962	0,1020
12 months	0,1206	0,1376

We see from **Table 7.1** that UIP outperform a Random Walk with drift for all maturities, ranging from 1 month to 12 months. We need to test if this is the case when we use a Random Walk without drift as well.

In the second analysis, we test if the UIP can outperform a Random Walk without drift. In this case we have removed the drift term $\hat{\delta}_{t,m}$ in the Random Walk, and therefore we also need to remove the constant $\hat{\alpha}_{m,t}$ in the UIP.

Random Walk: $$\Delta^m \hat{s}_{t+m|t} = 0 \quad (7.3)$$

UIP: $$\Delta^m \hat{s}_{t+m|t} = \hat{\beta}_{m,t}(i_t^m - i_t^{m*}) \quad (7.4)$$

TABLE 7.2 - RMSFE

	UIP	Random Walk
1 month	0,0379	0,0351
3 months	0,0657	0,0628
6 months	0,0979	0,0975
12 months	0,1215	0,1297

We see from **Table 7.2** that 1-month Random Walk without drift has the smallest RMSFE of 0,0351. Based on this result we choose to use Random Walk without drift as a benchmark in our further analysis. This is in line with exchange rate literature where the Random Walk model is a frequently used benchmark.

The UIP puzzle implies that $\hat{\beta}_{m,t}$ should be equal to one and $\hat{\alpha}_{m,t}$ should be equal to zero. When $\hat{\beta}_{m,t}$ is equal to one, then the cross-country interest rate differentials are equal to the expected exchange rate changes over the same horizon. We calculated $\hat{\beta}_{m,t}$ for UIP using rolling window, as explained in section 6.1. We see from the **Figure 7.1** below that in our data the $\hat{\beta}_{m,t}$ is far from one. The average value is 0,0038. This implies that the UIP is violated. Thus, the interest rate differentials are not important to explain the development of the exchange rate. The violation of the UIP in our analysis is consistent with the results of Chen and Tsang (2013). They found that UIP is systematically violated over a wide range of currency – interest pairs. They argue that the primary explanation for the UIP puzzle points to either the presence of time-varying risk premiums or systematic expectation errors.

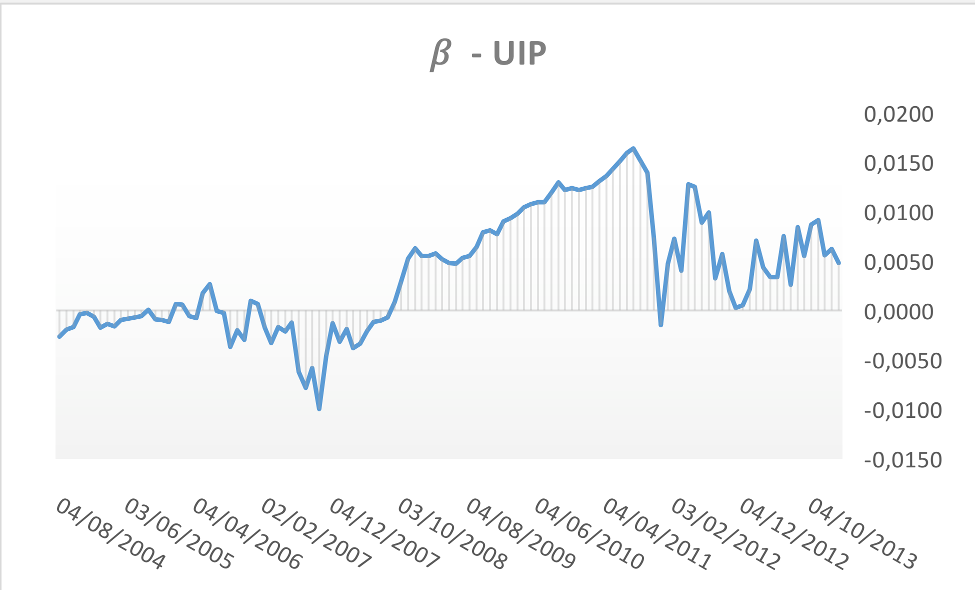

Figure 7.1: *The development of the UIP beta from August 2004 until October 2013.*

7.2 Overall Forecast Performance

We use RMSFE to measure the overall forecast performance. First, we will evaluate the overall performance of the first model, the Relative-Factors model. Second, we will evaluate the overall performance of the second model, the Six-Factors model. At the end we will present the analysis where we test the single factors (level, slope, curvature) and measure their overall forecast performance.

We will present the RMSFE of the alternative models relative to the benchmark, which is the Random walk, over a period of 1 to 12 months. A ratio smaller than 1 implies that the alternative model beats the Random walk.

7.2.1 Relative-Factors model

In the Relative-Factors model, we extract three Nelson Siegel factors (L^R, S^R and C^R) based on cross-country interest rate differentials between Norway and the US.

Benchmark: $\Delta^m \hat{s}_{t+m|t} = 0$ (7.5)

Alternative: $\Delta^m \hat{s}_{t+m|t} = \beta_{m,1} L_t^R + \beta_{m,2} S_t^R + \beta_{m,3} C_t^R$ (7.6)

TABLE 7.3 – RELATIVE RMSFE

1 month	3 months	6 months	12 months
1,0342	1,0334	1,1303	1,2837

We see from **Table 7.3** that the Relative-Factors model does not outperform the Random walk at any maturities. It is important to emphasize that at shorter horizon the Relative-Factors model forecasts almost as good as the Random Walk. The Random Walk is frequently found to generate better exchange rate forecasts than economic models, which is known as the Meese-Rogoff puzzle (Rossi 2013).

7.2.2 Six-Factors model

In the Six-Factors model we extract six Nelson Siegel factors, three for Norway (L^{NO}, S^{NO} and C^{NO}) and three for the US (L^{US}, S^{US} and C^{US}) as seen in **Equation (7.8).**

$$\text{Benchmark: } \Delta^m \hat{s}_{t+m|t} = 0 \tag{7.7}$$

$$\text{Alternative: } \Delta^m \hat{s}_{t+m|t} = \beta_{m,1} L_t^{NO} + \beta_{m,2} S_t^{NO} + \beta_{m,3} C_t^{NO} + \beta_{m,4} L_t^{US} + \beta_{m,5} S_t^{US} + \beta_{m,6} C_t^{US} \tag{7.8}$$

TABLE 7.4 – RELATIVE RMSFE

1 month	3 months	6 months	12 months
1,1396	1,2245	1,3990	2,5520

We see from **Table 7.4** that the Six-Factors model does not outperform the Random Walk at any maturities, similar to the Relative-Factors model. If we compare the results from **Table 7.3** and **7.4,** we see that the Relative-Factors model is closer to outperform the Random Walk model with smaller RMSFEs.

The reason why the models do not outperform the Random Walk could be that there are certain periods where the models make bad forecasts, and this has a substantial effect on the overall performance. We will look at how the models perform over time when analyzing the second forecast evaluation statistic, the CSSED.

7.2.3 Analyzing the Single Factors

In addition to the alternative models, we have tested the overall forecast performance of the single factors in the two models. This means that we have tested the forecast performance of the level factor, slope factor and curvature factor respectively at 1 month and 3-month maturity for both the Relative-Factors model and the Six-Factors model. We start with the Relative-Factor model and we present the RMSFE of the single factors relative to the benchmark.

TABLE 7.4 – RMSFE SINGLE RELATIVE FACTORS		
	1 month	3 months
Level	1,0199	1,0080
Slope	1,0028	0,9873
Curvature	1,0228	1,0175

TABLE 7.5 – RMSFE SINGLE FACTORS		
	1 month	3 months
Level (NO)	1,0114	1,0080
Slope (NO)	1,0085	0,9777
Curvature (NO)	1,0313	1,0111
Level (US)	1,0114	1,0080
Slope (US)	1,0228	1,0175
Curvature (US)	1,0171	1,0096

The relative slope factor (**Table 7.4**) and the Norwegian slope factor (**Table 7.5**) outperform the Random Walk at a 3-month maturity. The slope factor has a stronger power to predict the exchange rate compared with the level and curvature factors. We know from the literature that the slope factor predicts fluctuations in real economic activity and inflation (Chen and Tsang 2013). A flatter yield curve is a signal for an economic slowdown or a forthcoming recession. One reason why the slope factor is a good predictor when forecasting the exchange rate is that it is countercyclical, like the risk-premium (Lustig et. al 2014). According to Chen and Tsang, a flatter yield curve predicts subsequent home currency appreciation and a high home currency risk-premium. When the economy is expecting an economic downturn or a forthcoming recession, this would induce higher perceived risk associated with holding the domestic currency. This would increase the excess currency return – the risk premium associated with holding domestic currency. The risk-premium increases because the agent need to get more compensation for undertaking risk in an unsecure market.

7.3 Forecast Performance Over Time

In the previous section, we revealed some motivating results that may be of interest when studying the relationship between the yield curve and currency risk premium. The relative slope-factor and the slope-factor for Norway, both at three-month horizon, consistently outperform the Random Walk model. In this section, we analyse their forecast performance over time by computing the CSSED. As explained earlier, increasing values of CSSED indicate that the alternative model outperforms the benchmark model. Since we have tested several different combinations of factors in the two main models, we choose to comment the forecasting performance over time for particular models that we believe have some interesting insights.

We will first consider the models that outperform Random Walk when studying the relative RMSFE. Later in the paper, we will comment on other combinations that reveal interesting results when studying their forecasting performance over time. You can find all of our models in the Appendix in section 11.

We start by analysing the forecast performance for the model in **Figure 7.4**. As we can see from the graph, the model has an increasing CSSED for several periods of time.

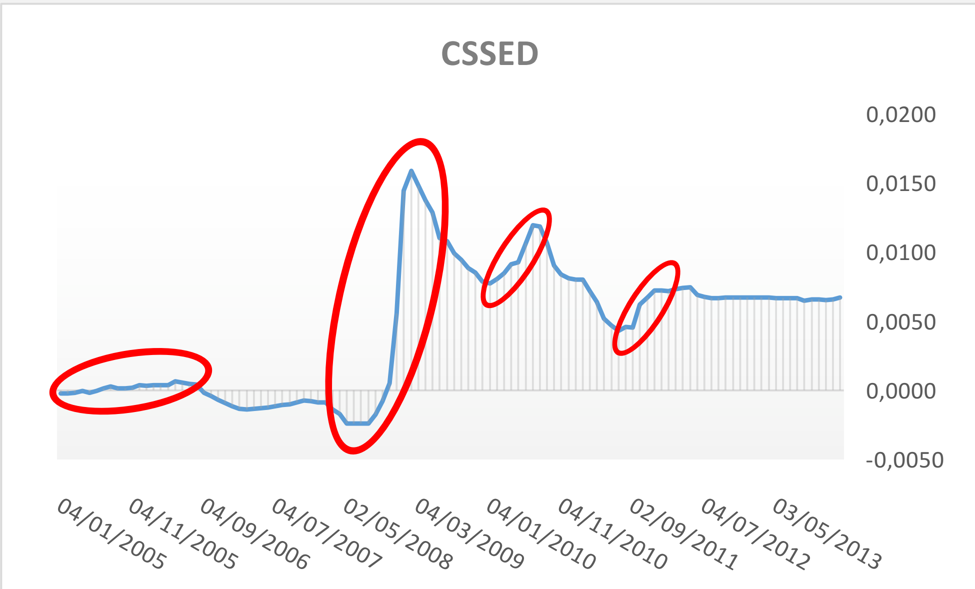

Figure 7.4: *The cumulative sum of squared forecast error difference of the Relative-Factors model for the slope factor at three-months horizon.*

Evidently, we see that the predicative performance of the model improves in the beginning of the time period considered, and especially in the third quarter of 2008. This pattern can also be seen in **Figure 7.6,** which also outperforms the benchmark model. The prediction of a steep US dollar appreciation against the Norwegian krone during this period is observable in **Figure 7.5.** The figure illustrates the exchange rate movements of Norwegian krone against the US dollar. What is interesting about this period is that the US investment bank Lehman Brothers filed for bankruptcy, and led the financial crisis of 2007-2009 to enter a serious phase. The global market became more volatile and unstable as uncertainty about the state of the global economy and financial conditions increased sharply (Kohler, 2010). Once the Lehman Brothers filed for bankruptcy, there were significant changes in the movements in exchange rates, although these movements reversed after a short period of time. They reflected the rise in risk aversion and changes in investors´ expectations about the risk of investing in particular currencies. One would think that during periods of crisis and uncertainty about future economic and financial conditions, one would have poor forecasts of the exchange rate. However, our models disprove this and predict better than the Random Walk model during the recent financial crisis. In the mid-2008 the US dollar appreciated sharply, which was predicted by the models. This might have been the case of luck, but we will try to discuss why our models manage to capture this event better than the Random Walk model. We will elaborate some of the contributors to the significant US dollar appreciation of 2008 based on a paper by McCauley and McGuire (2009).

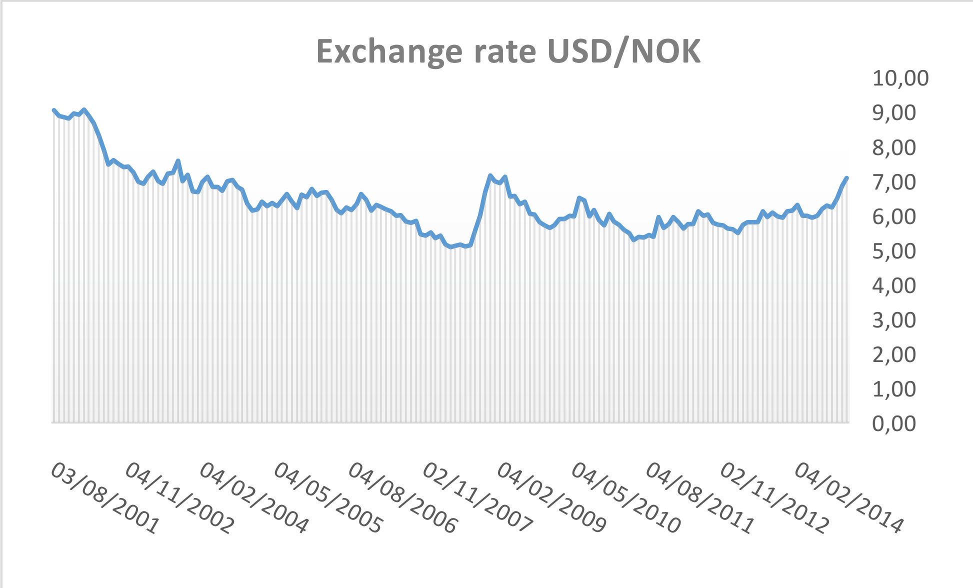

***Figure** 7.5: Exchange rate movement of the US dollar against the Norwegian kroner from third quarter 2001 to fourth quarter 2014.*

The first contributor that we consider to have had an effect is the safe haven currency phenomenon. The most common definition of a safe haven currency is investors´ preferred currency when there is a high risk aversion in the financial market. It could mean either an asset with low risk or high liquidity, with the intention of reducing investment losses. In other words, investors escaped the crisis-country and invested in “safe” currencies. Typically, these currencies will appreciate during times of high market volatility and declining equity prices, and show the opposite effect when there is low market volatility and increasing equity prices (Flatner, 2009). The recent financial crisis in the US is a special case. The safe haven currency mechanism went against its typical pattern of crisis-related flows. The turmoil in the financial market created risk aversion among investors, and consequently led to global flight to safety *into* US Treasury bills. Increased demand for these securities contributed to the sharp US dollar appreciation against many currencies during the third quarter of 2008, as illustrated in **Figure 7.5**. And the Norwegian Krone was no exception.

The second contributor we believe is the interest rate differentials, which may have played a significant role in explaining the exchange rate movements (Kohler, 2010). One important channel of the interest rate differentials is the effects from carry trade. Investors hold a high-yield (target) currency asset that is financed by a low-yield (funding) currency liability. As discussed in section 2.4, this investment strategy is profitable when there are deviations from the UIP; investors make abnormal profits from the trade if the interest rate differential is not entirely offset by an appreciation of the funding currency. The financial stress in 2007-2009 contributed to investors' reduced appetite for risk, and this changed their behaviour. The decline in yield differential and the decreased number of carry trades contributed to the sharp increase in the US dollar exchange rate.

As we have discussed, increased uncertainty and high volatility in the financial markets affected agents´ expectations during the crisis. One of the outcomes was loss of trust to banks and this resulted in depositors withdrawing their money. Hence, banks' liquidity reduced drastically, which raised the borrowing rate in the money market (interbank rate). This led to NIBOR and the Norwegian krone being more exposed and sensitive to global financial stress and changes in agents' expectations for the banks. This was evident in the recent financial crisis as the NIBOR rate, along with the Federal Funds rate, experienced a sharp increase, and the Norwegian Krone depreciated. The Federal Funds rate is the rate that a depository institution lends funds preserved by the Federal Reserve to another depository institution overnight. It is viewed as the most important rate that regulates the level of all other interest rates in the US economy.

As the Norwegian data used in our model is based on the NIBOR, this increase can be observed in the Norwegian short-term yields. However, when examining the US short-term yields, there is rather a decline during the same time period. As the model in **Figure 7.4** consider Norwegian yields relative to US yields, our model manages to capture these movements in the yield curves.

Although the model experiences a sharp increase in the CSSED over a short period of time during the financial crisis, it might be pure coincidence. A relatively good predicative model outperforms the benchmark model over longer periods of time. The two following figures that we will discuss in further detail are evidence of this.

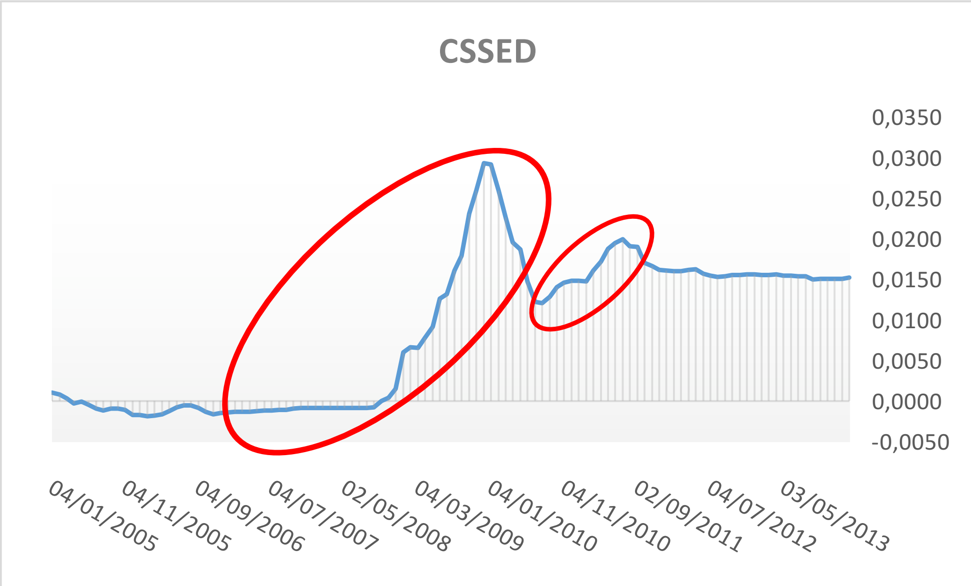

Figure 7.6: *The forecast performance over time by illustrating the cumulative sum of squared forecast error difference of the three-months horizon for the slope factor for Norway.*

Figure 7.6 illustrates the forecast performance over time for the slope factor in Norway at three-month maturity. The CSSED increases for more than three years up to the fourth quarter of 2009. The exchange rate movements during this period is characterized by two different phases. The first period (quarter four 2006 to quarter three 2008) indicates US dollar depreciation against the Norwegian kroner. The second period (quarter three 2008 to quarter four 2009) illustrates first a sharp US dollar appreciation before a quick and strong reversal of the appreciation. The model succeeds in predicting these movements better than the Random Walk model. To fully understand this, we analyze the slope factor in the model. As mentioned earlier, the slope factor is the short-term interest rates that explains the activity in the output. Examining the movements of the factor for Norway our results uncover increasing values for the slope in the first period, while varying values in the second period. We have the following interpretation. An increase in the slope factor indicates a forthcoming recession, which is true as the period considered covers the start of the financial crisis of 2007-2009. The increased financial stress contributed to a decline in output activity and a depreciating Norwegian krone.

We have the same interpretation for the second period as well; the value of the slope factor is varying together with the exchange rate. However, we do not see the same for the slope factor model for the US. We conjecture that this could be due to the fact that the US was more affected by the global financial crisis of 2007-2009. The Federal Funds rate declined sharply and was close to zero for a long period of time, while NIBOR declined gradually and stabilized at a higher level.

When evaluating the out-of-sample performance by using the relative RMSFE, we have seen that it is valuable to look at the forecast performance over time as it may reveal important results. This is absolutely the case for the models we will discuss in the next pages. Although their relative RMSFE performance is not one of the

As we can see from **Figure 7.7**, the CSSED for the Relative-Factors model at three-months horizon is shifting over time.

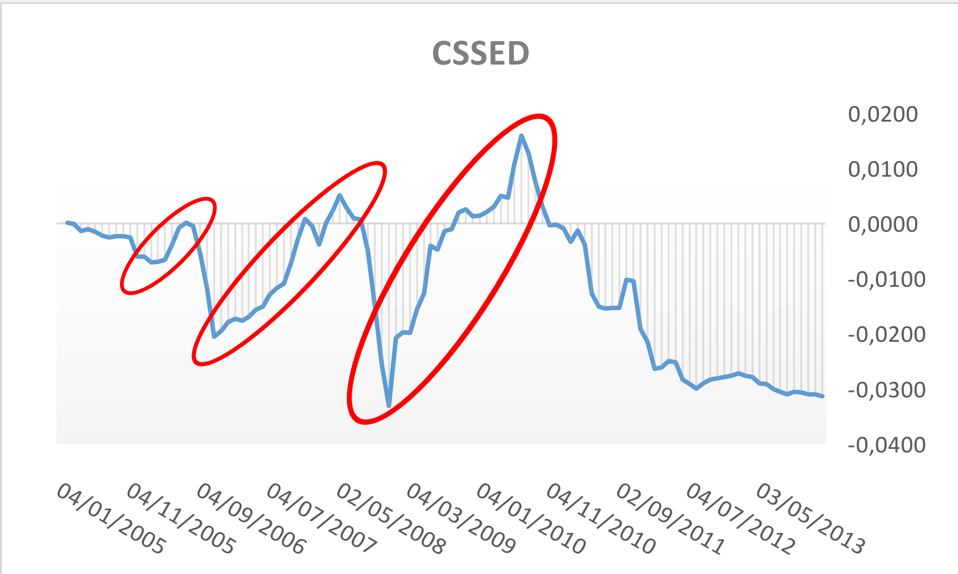

Figure 7.7: *The forecast performance over time by illustrating the cumulative sum of squared forecast error difference of the Relative-Factors model at three months maturity.*

There are periods where the CSSED has sharp and quick decreases, but the interesting feature is the long periods of increased CSSED. To explain these movements better, we have looked into the patterns of the betas for the three relative factors during the periods of an increasing CSSED. We have three periods where the Relative-Factors model does better than the Random Walk model at three months' horizon.

The first period is from second quarter 2006 to third quarter 2006, and it is characterized by decreasing and negative relative level beta and relative curvature beta. On the other hand, the relative slope beta is increasing and positive. The second period persists over two years and begins in the fourth quarter of 2006 and throughout third quarter of 2008. We have similar pattern for the relative level beta here as well – decreasing and negative. The relative curvature beta is somewhat different. It starts with positive values and keeps decreasing into negative values. Considering the pattern of the relative slope beta, we see that it is unclear, but it stays positive during this period. Lastly, the third period of increasing CSSED begins in fourth quarter 2008 and lasts until third quarter 2010. In this case, we also have the same situation for the relative level and relative curvature betas as in the second period. In addition, the relative slope beta is increasing and positive. Observing quite similar patterns for the three relative betas during the periods mentioned. We believe that these patterns might help us to understand and predict the exchange rates better.

As explained earlier in the paper, we expect short-term yields to have more fluctuations as it responds quickly to shocks, which can be seen in the graph. Hence, the model captures the significance of several events during the period from 2005 to 2013, and for this reason, the CSSED is more volatile. For more than three years, the Relative-Factors model at three-month horizon has a better forecast performance than Random Walk model with same maturity.

In section 7.3, the relative RMSFE for the six-month horizon Six-Factors model was 1.3990, which implies that the Random Walk model has a better overall forecast performance. However, by examining the forecast performance over time we postulate some interesting explanations.

Figure 7.8: *The forecast performance over time by illustrating the cumulative sum of squared forecast error difference of the six-months horizon Six-Factors model.*

Figure 7.8 illustrates, in particular, two long and stable periods of increasing CSSED value. The first interval persists for approximately three years up to the end of first quarter 2009, while the second interval persists from second quarter 2010 until second quarter 2012. Nevertheless, the big decrease in CSSED during the recent financial crisis is significantly strong and the effects of it are evident in the models´ forecasting performance. We argue that this occurrence is most probably the cause for the model having a high relative RMSFE, and for this reason reduces the model's overall performance.

Further, we see similar patterns in **Figure 7.9**. The Relative-Factors model for the level factor at one-month horizon has two relatively long periods with increasing values of CSSED.

Figure 7.9: *The forecast performance over time by illustrating the cumulative sum of squared forecast error difference of the One-month horizon Relative-Factors model for level.*

The model has a good forecasting accuracy, where the two periods combined forecast approximately five years, of the period observed. Our interpretation of the results is as following. As previously discussed, the level factor is a macroeconomic interpretation for the expected long-run inflation. Increasing level factor indicates higher future inflation, which is the case for the first period observed (fourth quarter 2005 to second quarter 2008). This period is characterized by the housing price boom in the US in early 2006 where the housing prices were substantially higher than their real value, among other things. Easily accessible loans contributed to the effect, and inflation more than doubled from 2004 to 2006. The following period indicates a short and sharp decrease in CSSED, which contributed to the reason why the model has a poor overall forecasting performance.

8 DISCUSSION

We use the work of Chen and Tsang (2013) as motivation for our analysis. They used in-sample predictive regression to show that the yield curve factors predict exchange rate movements and explain excess currency return one month to two years ahead. To complement the in-sample predictive regression they conducted a rolling out-of-sample forecast to see how the yield curve model forecasts future exchange rate changes. To evaluate the out-of-sample forecast performance they compared the factor model to the Random Walk model and the interest differential model (UIP). They found that the factors model did not consistently outperform the two benchmarks.

We know from literature than when the market expects a decline in output in a foreign country this is consistent with a flatter slope. A flatter foreign yield curve predicts subsequent foreign currency appreciation. The low payoff from the foreign currency makes it a bad hedge and a risky asset, which must increase the excess currency return – the risk premium associated with holding foreign currency.

Our finding that the risk premium increases with a flatter slope also offers a feasible explanation to the UIP puzzle. We will look at an example, where the foreign short-term interest rate (i*) increases, to illustrate this. When i* increases the foreign yield curve gets flatter (assuming that long-rates does not respond). If the home yield curve stays fixed, the increase in the foreign short-term interest rate would increase the risk premium, as we explained above. If the rise in the risk premium is large enough, then the Δs_{t+m} can turn positive. This means that the foreign currency would appreciate in response to a rise in foreign interest rates, which is contradictory to the UIP literature. This result points to an omitted-variable bias problem in the original UIP regression. Since the risk premium is negatively correlated with the interest differentials, omitting this term would make the estimated coefficient for the interest differential term biased. Chen and Tsang (2013) observed that the relative factors, embodying current expectations about future economic dynamics, have a declining impact on ex post risk premiums over longer horizons. This indicates that the long-horizon exchange rate movements are less affected by the risk premium. Their results show that at longer-maturity rates the UIP puzzle can disappear.

We see from our results that it is difficult to beat the Random Walk in exchange rate forecasting. This is in line with the Meese-Rogoff puzzle, which states that exchange rate models cannot outperform the Random walk in out-of-sample forecasting. One reason why the Random walk is so hard to beat is because how we measure forecast accuracy. Several researchers state that the forecast accuracy measure rely too much on the forecasting error, rather than how the model predict the direction of change. This is in line with Engel et al. (2007) which state that beating the Random walk in forecasting the exchange rate is too strong a criterion for accepting the alternative model. They suggest that exchange rate models are not that bad, even though they do not outperform the Random walk model.

From theory we know that the Nelson-Siegel factors contain information about future economic activity. We have shown that the Nelson-Siegel factors might be valuable when forecasting the exchange rate. Our two models, the Relative-Factors and the Six-Factors model, do not outperform the Random Walk model, but they are not far off. If we look at the results from **Table 7.3** and **7.4,** we see that our models predict almost as good as the Random Walk model, with values slightly exceeding one. If we look at the factors isolated, we see that the slope factor predicts the exchange rate better than the Random Walk model. As discussed earlier in the paper, a flatter domestic yield curve is a signal for an economic downturn at home. When the slope factor increases (flatter yield curve) the risk premia associated with holding domestic currency increases. Cochrane and Piazzesi (2009) found the same mechanism in the bond market. When the slope factor is large (flat yield curve) it forecasts a rise in future expected bond returns and the risk premia increases. This is very interesting and underlines that there are some factors that affect both the exchange rate market and the bond market.

9 CONCLUSION

We find that the Nelson-Siegel factors extracted from the yield curves contain information about future exchange rate movements. Our models do not outperform the Random Walk model in the overall period considered. However, we find evidence of beating the Random Walk model in certain periods of time. An interesting finding is that the slope factor (Norwegian and relative) predicts the exchange rate better than the Random Walk at a three-months' horizon during the financial crisis of 2007-2009. This may be pure coincidence. We therefore encourage other researchers to analyse this further by looking at a larger dataset containing several financial crises. In addition one could perform carry trade strategies with the different models to compare which one yields higher profits. It would also be interesting to include other currency pairs, for instance NOK-EUR.

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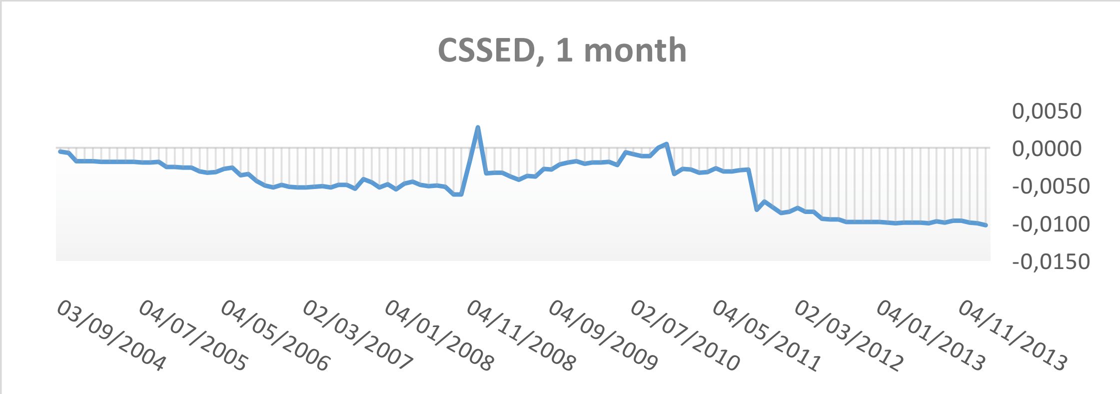
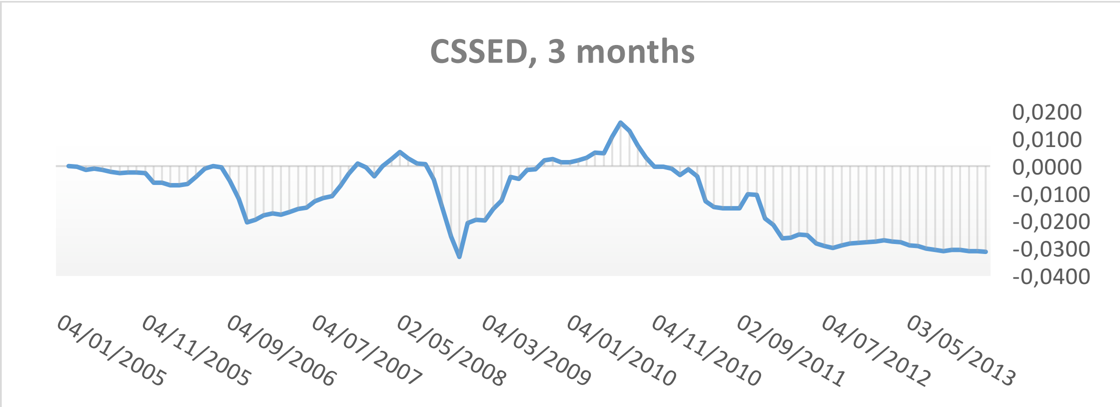
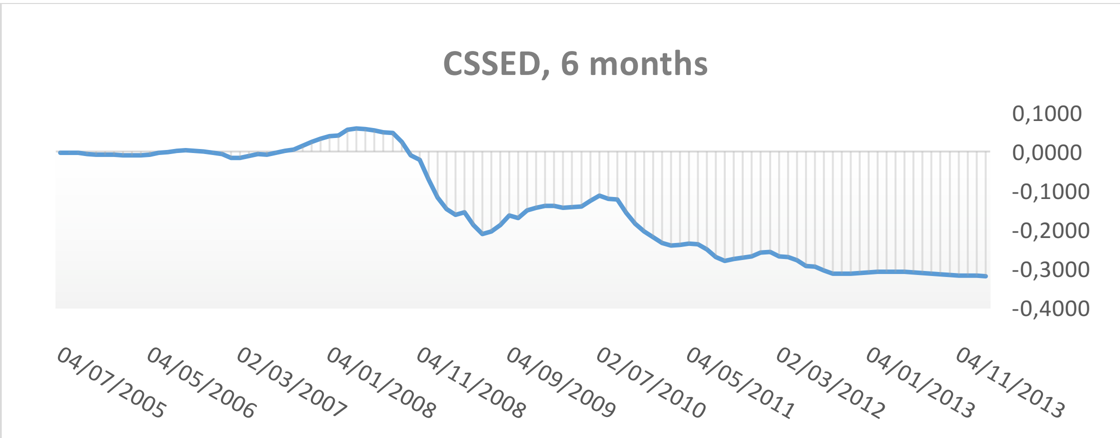
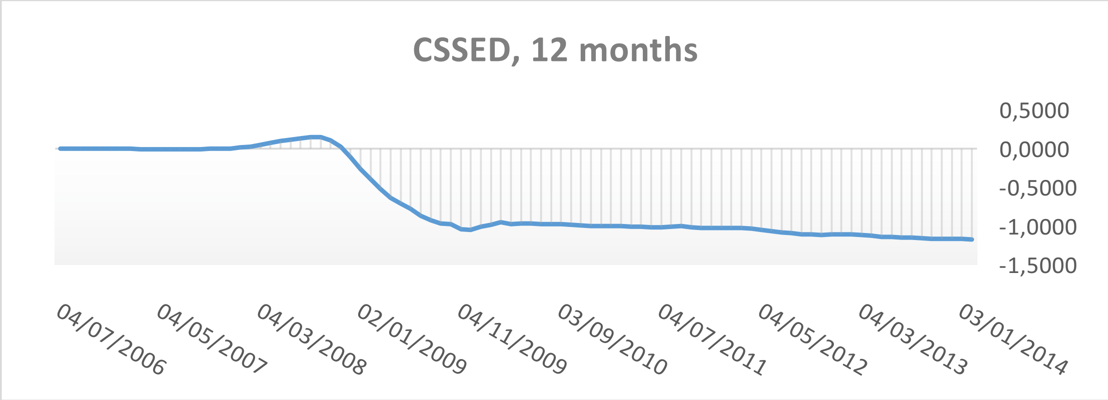
11 APPENDIX

Relative-Factors model (one month, three months, six months, and twelve months respectively):

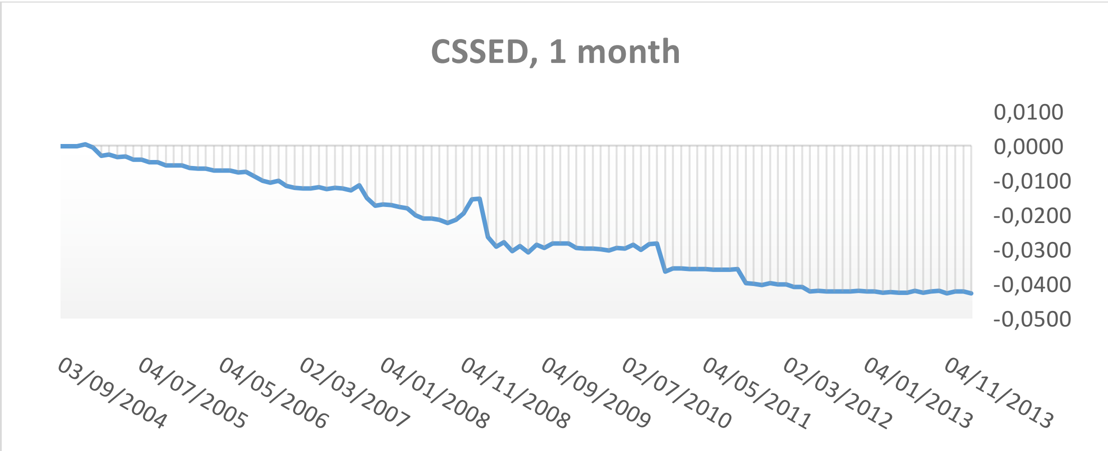


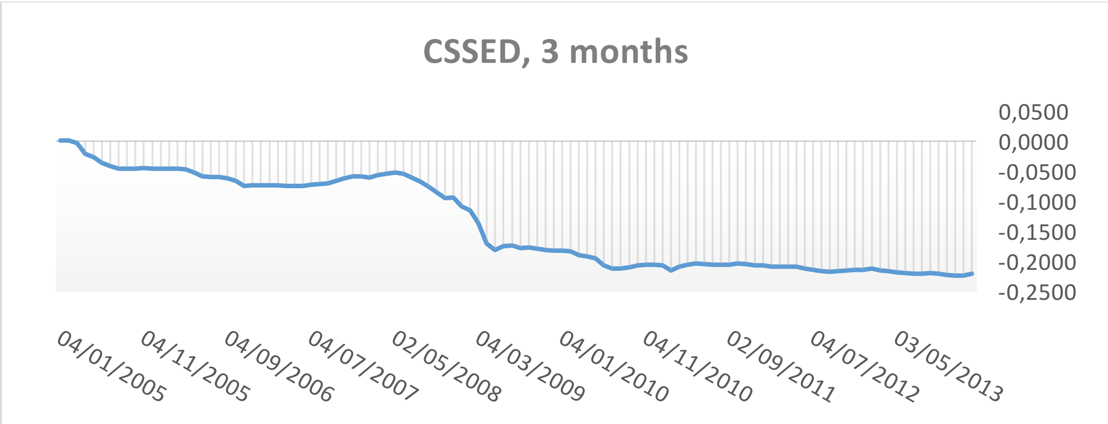


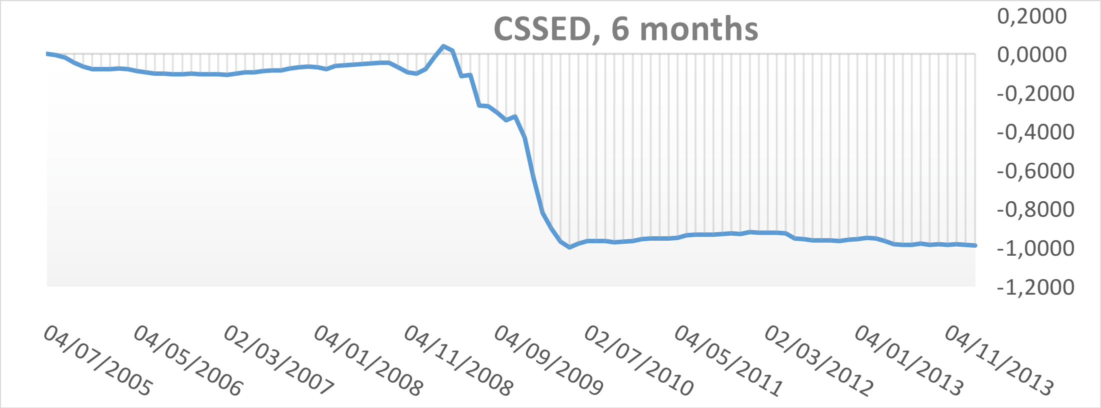


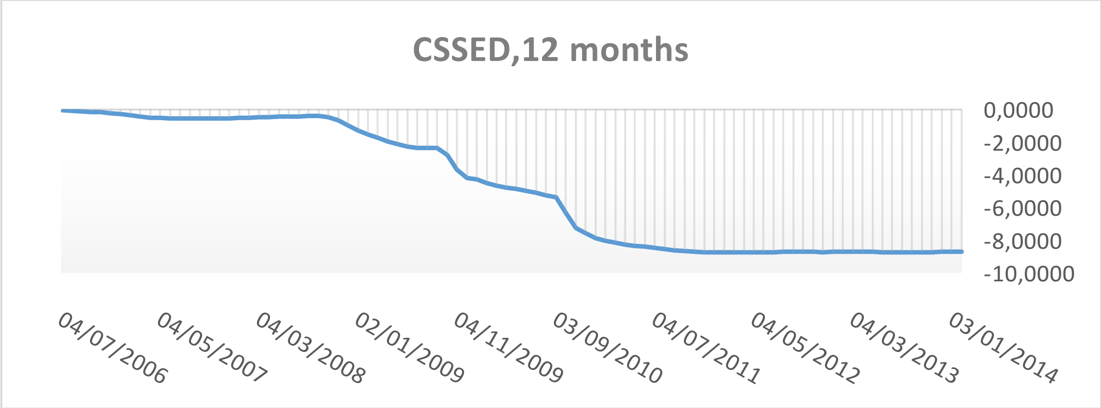


Six-Factors model (one month, three months, six months, and twelve months respectively):



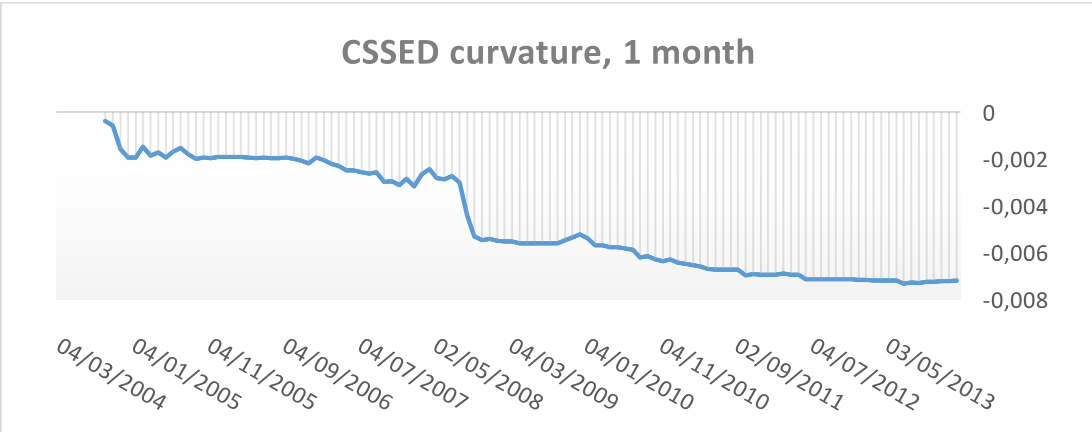






Single factors in the Relative-Factors model:


CSSED slope, 1 month
0,008
0,006
0,004
0,002
0
-0,002
04/03/2004
04/01/2005
04/11/2005
04/09/2006
04/07/2007
02/05/2008
04/03/2009
04/01/2010
04/11/2010
02/09/2011
04/07/2012
03/05/2013


CSSED curvature, 1 month
0
-0,002
-0,004
-0,006
-0,008
04/03/2004
04/01/2005
04/11/2005
04/09/2006
04/07/2007
02/05/2008
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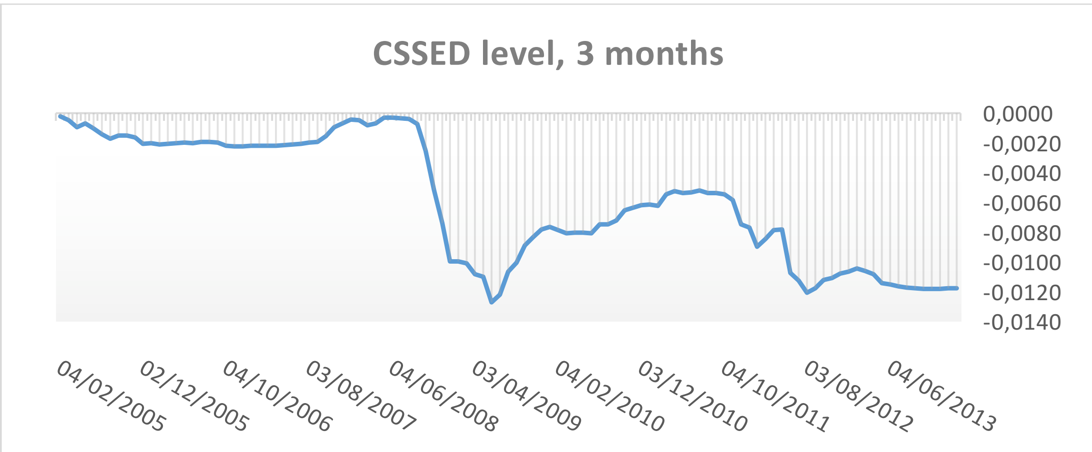
02/09/2011
04/07/2012
03/05/2013


CSSED level, 3 months
0,0000
-0,0020
-0,0040
-0,0060
-0,0080
-0,0100
-0,0120
-0,0140
04/02/2005
02/12/2005
04/10/2006
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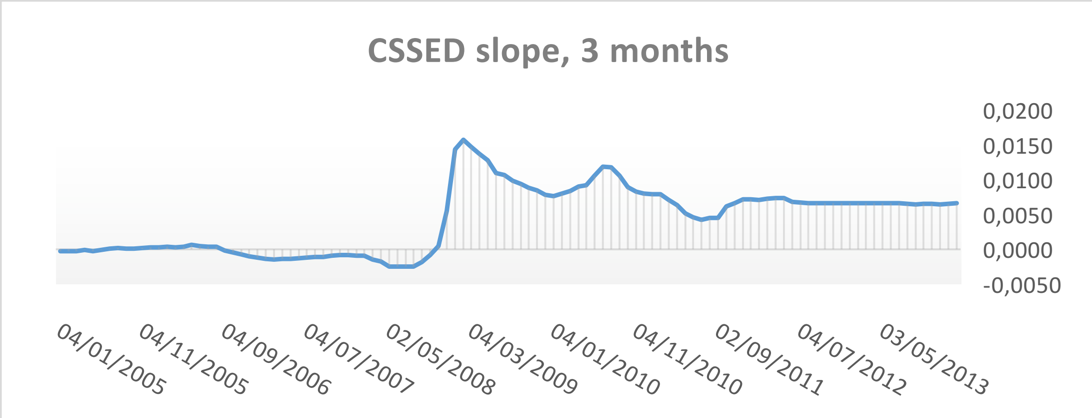
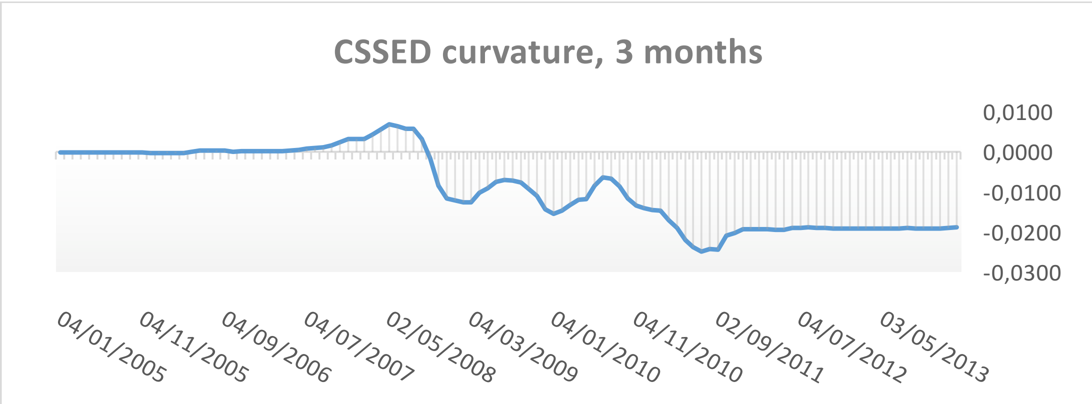
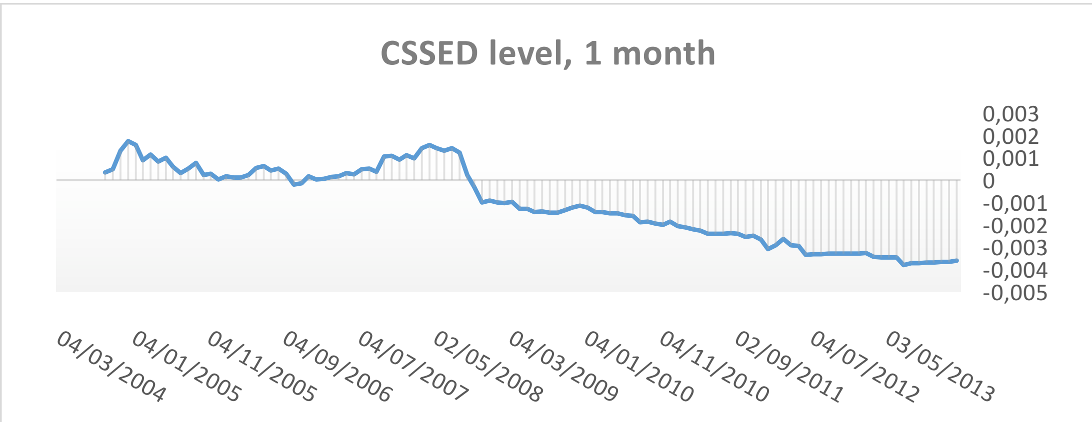
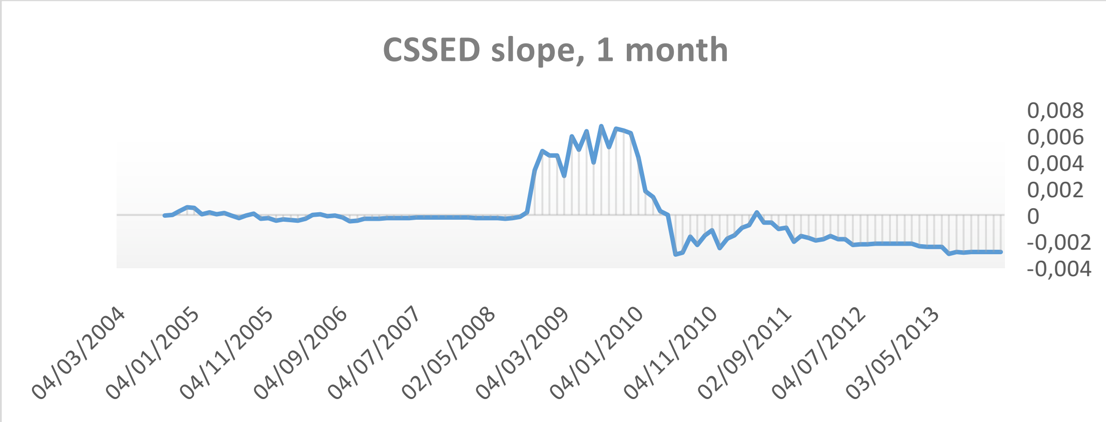
04/10/2011
03/08/2012
04/06/2013

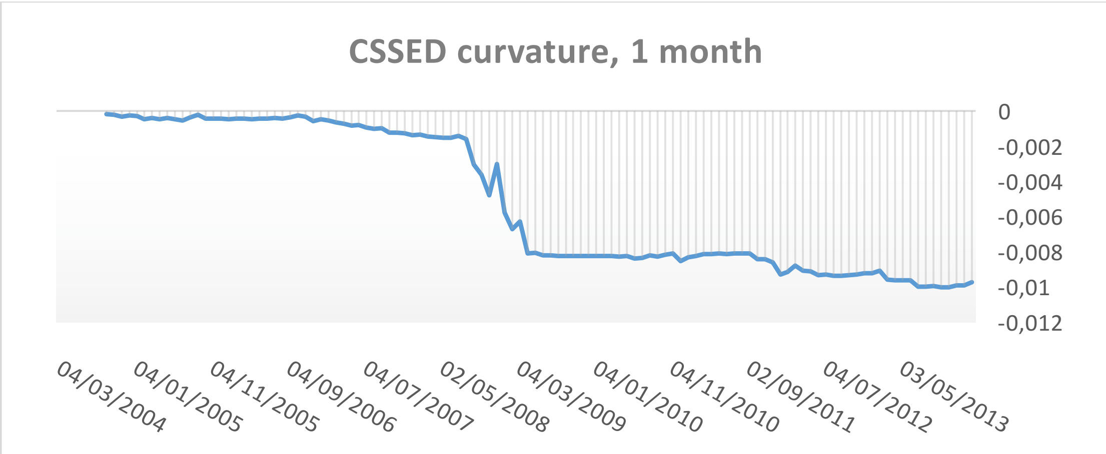




Single factors for Norway in the Six-Factors model:




CSSED slope, 1 month
0,008
0,006
0,004
0,002
0
-0,002
-0,004
04/03/2004
04/01/2005
04/11/2005
04/09/2006
04/07/2007
02/05/2008
04/03/2009
04/01/2010
04/11/2010
02/09/2011
04/07/2012
03/05/2013


CSSED curvature, 1 month
0
-0,002
-0,004
-0,006
-0,008
-0,01
-0,012
04/03/2004
04/01/2005
04/11/2005
04/09/2006
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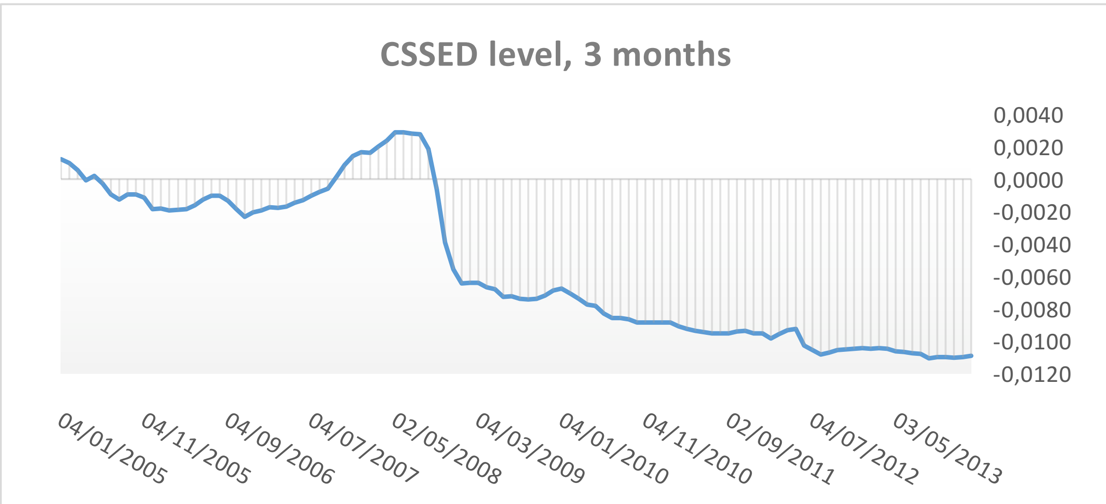
02/05/2008
04/03/2009
04/01/2010
04/11/2010
02/09/2011
04/07/2012
03/05/2013


CSSED level, 3 months
0,0040
0,0020
0,0000
-0,0020
-0,0040
-0,0060
-0,0080
-0,0100
-0,0120
04/01/2005
04/11/2005
04/09/2006
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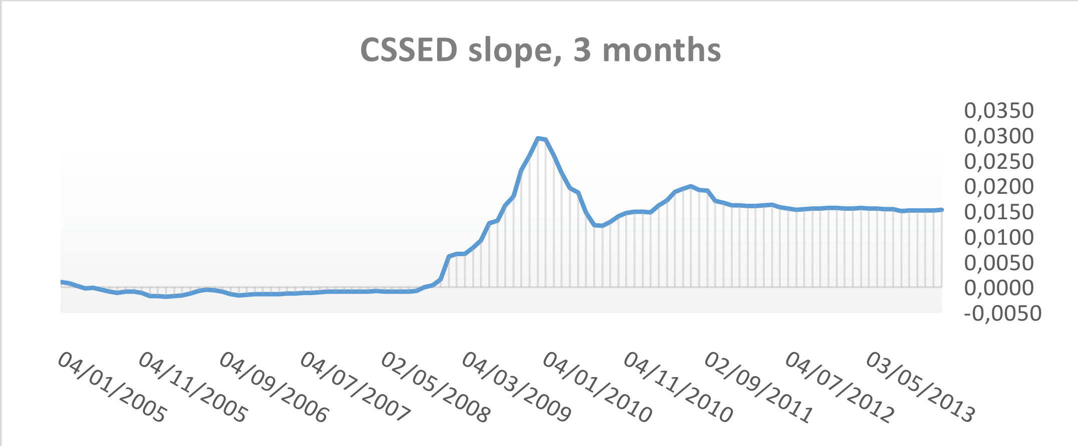
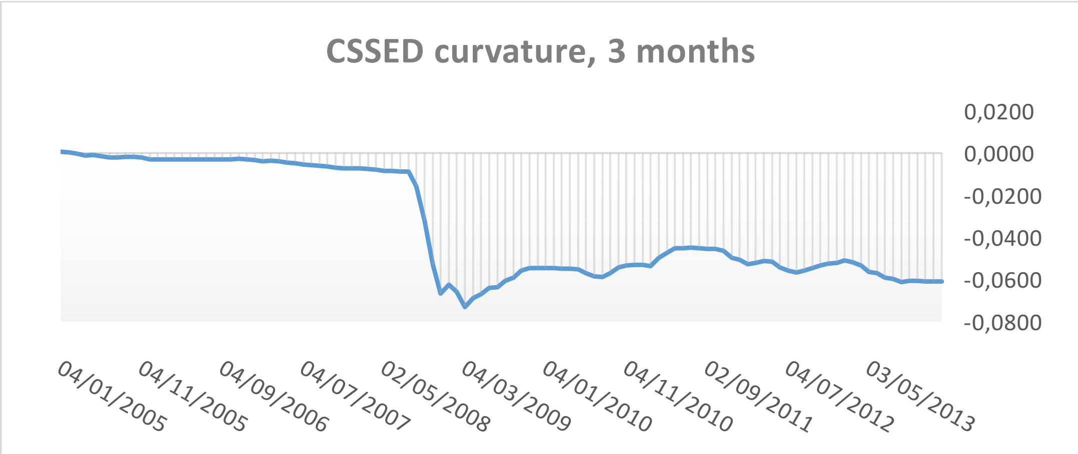
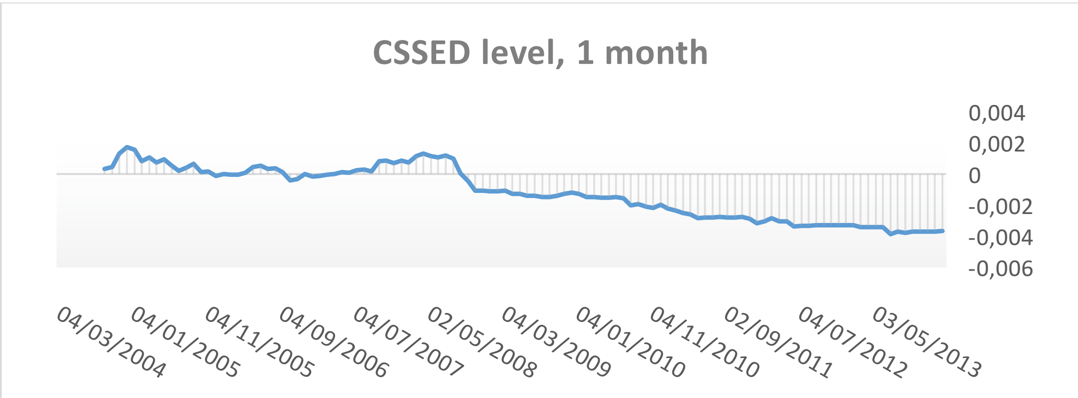
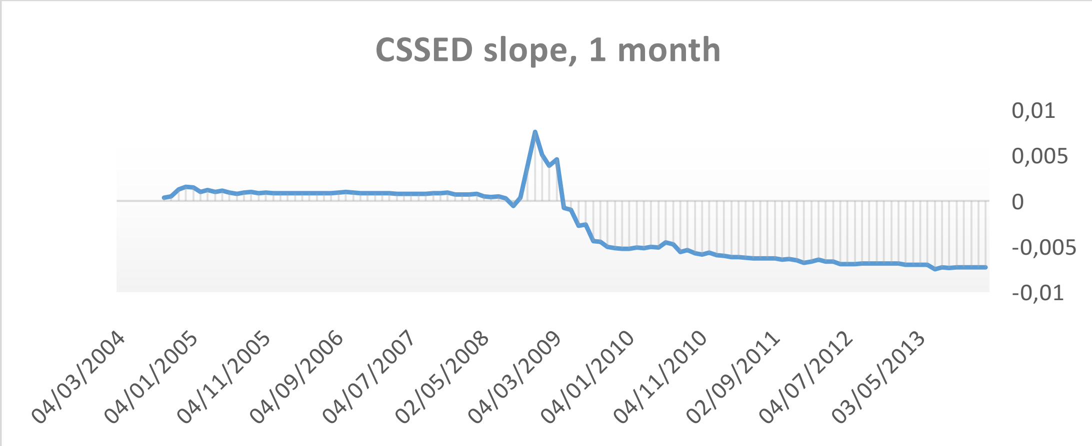
04/07/2012
03/05/2013





Single factors for the US in the Six-Factors model:




CSSED slope, 1 month
0,01
0,005
0
-0,005
-0,01
04/03/2004
04/01/2005
04/11/2005
04/09/2006
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02/05/2008
04/03/2009
04/01/2010
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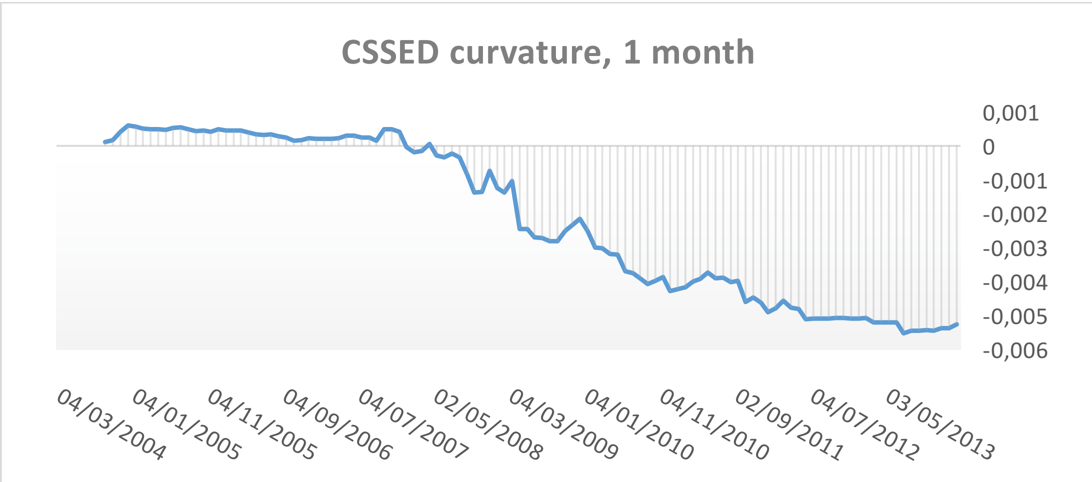
02/09/2011
04/07/2012
03/05/2013


CSSED curvature, 1 month
0,001
0
-0,001
-0,002
-0,003
-0,004
-0,005
-0,006
04/03/2004
04/01/2005
04/11/2005
04/09/2006
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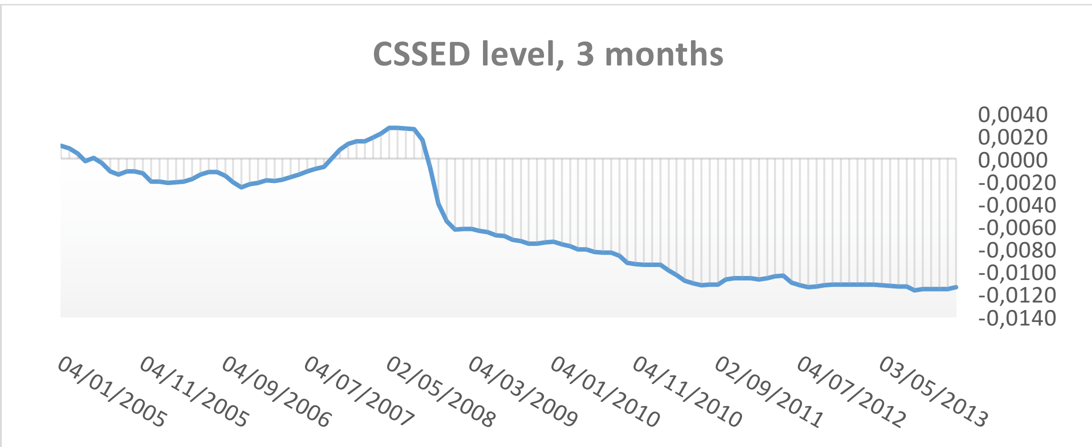
02/09/2011
04/07/2012
03/05/2013


CSSED level, 3 months
0,0040
0,0020
0,0000
-0,0020
-0,0040
-0,0060
-0,0080
-0,0100
-0,0120
-0,0140
04/01/2005
04/11/2005
04/09/2006
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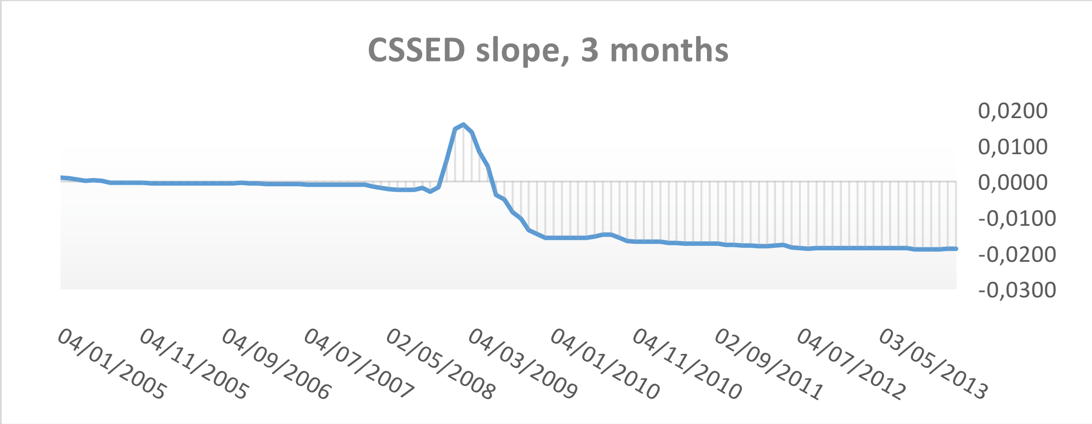
04/07/2012
03/05/2013


CSSED slope, 3 months
0,0200
0,0100
0,0000
-0,0100
-0,0200
-0,0300
04/01/2005
04/11/2005
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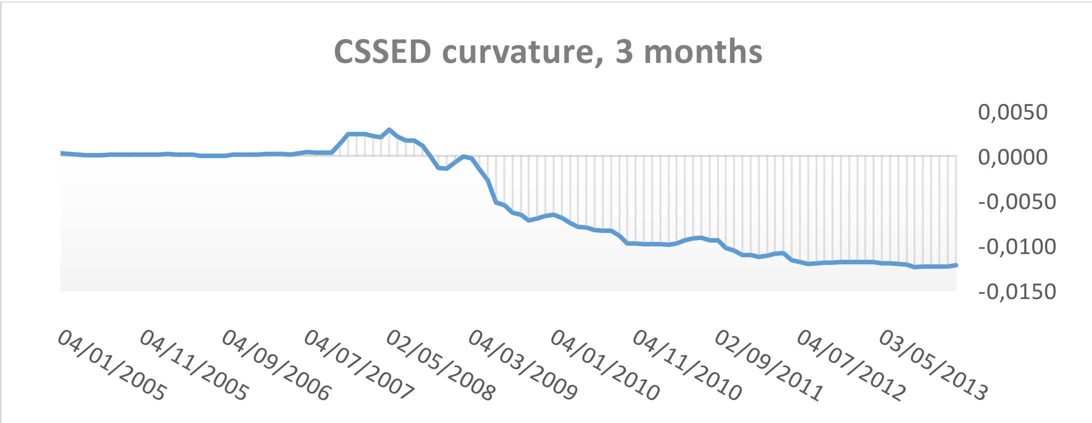
04/07/2012
03/05/2013


CSSED curvature, 3 months
0,0050
0,0000
-0,0050
-0,0100
-0,0150
04/01/2005
04/11/2005
04/09/2006
04/07/2007
02/05/2008
04/03/2009
04/01/2010
04/11/2010
02/09/2011
04/07/2012
03/05/2013