JÖNKÖPING UNIVERSITY
International Business School

Uncovered Interest Parity and the Financial Crisis of 2007

An econometric study of the robustness of the uncovered interest parity over different time periods, with varying economic stability.

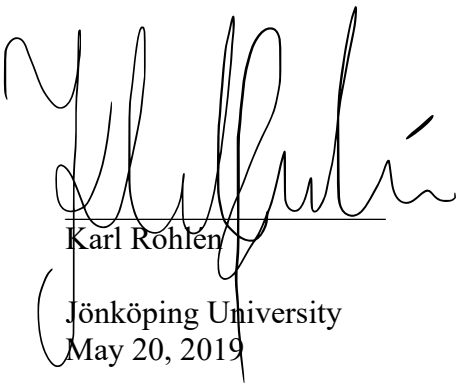
BACHELOR THESIS WITHIN: Economics
NUMBER OF CREDITS: 15 ECTS
PROGRAM OF STUDY: International Economics
AUTHOR: Karl Rohlén & Pontus Ekdahl
JÖNKÖPING May 2019

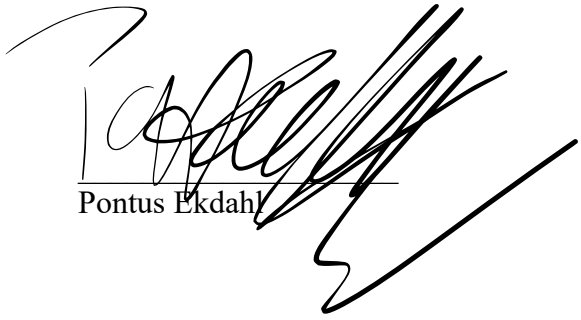
Acknowledgements

We, Karl Rohlén and Pontus Ekdahl, would like to take the possibility to give our acknowledgments to some individuals for the support and guidance that made this paper possible.

We would like to express our gratitude and thank our supervisor Kristofer Månsson for his guidance, valuable suggestions, and useful critique when writing this paper. Advice from Kristofer has been the key when conducting our research.

A special thanks is also extended to our family and friends who have given us their support and encouragement throughout the process.





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May 20, 2019

Bachelor Thesis within Economics

Title: Uncovered Interest Parity and the Financial Crisis of 2007
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Tutor: Kristofer Månsson
Date: 2019-05-20

Key terms: Uncovered interest parity, interest parity, interbank offering rates, yield to maturity, short-horizon, long-horizon

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Abstract

The current intellectual climate regarding economics seems to be at an agreement regarding the theory of uncovered interest parity and its unreliability within real life application. The purpose of this thesis is to test how the theory holds over periods with varying economic stability, both using a short- and long-horizon test in order to establish the usefulness of uncovered interest parity as a predictor for exchange rate movements. The short-horizon test will utilize the interbank offering rate, and the long-horizon test the yield to maturity of government 10-year benchmark bonds as the interest rate. The sample period is 2000 to 2018, covering the financial crisis of 2007. We will focus on three different time periods: pre-crisis, crisis and post-crisis. We will use ordinary least squares (OLS) regression and an extreme sampling. From the regressions we conclude that most of the time periods move against the uncovered interest parity, where only the crisis period is in line with the theory. The extreme sampling supports this result, as larger interest differentials provide the rational expectations with more predictive power of the future spot exchange rate.

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1. Introduction

In this paper we will be performing an analysis of the economic theory uncovered interest parity (UIP), to see if the theory holds in different economic climates. To test this, we have chosen to use the time period 2000 to 2018, as it includes one of the most erratic time periods of modern economics – the financial crisis of 2007 (Crotty, 2009). The theory will be tested between the United States and the Scandinavian countries; Denmark, Iceland, Norway and Sweden, where the United States will serve as the base country. For this purpose, we will use OLS regressions to observe how UIP holds, by testing the relationship between the change in the spot exchange rate and the interest rate differentials. The interest rates used are the interbank offering rates (IBOR's) and the yield to maturity of government 10-year benchmark bonds. The different maturities of the interest rates enable us to test the theory both at a short-horizon using the IBOR's, and at a long-horizon using the yield to maturity of the bonds. This is done, as we expect the theory to hold better in the long-run, rather than in the short-run. Further, we will also implement an extreme sampling to test the interest rate differentials. Lastly, a rolling regression is also used to test the stability of the estimates over time, and how the sample size affects the estimates. As a result, we found that UIP held better throughout the crisis period, indicating that economic fluctuations produce better estimates.

The interest rate parity condition is far from a new concept, it was discussed by both Ricardo (1811) and Cournot (1838). It was Keynes (1923) that popularized the theory, by the creation of covered interest parity (CIP) that he presented in his work *A tract on monetary reform* (Cieplinski & Summa, 2015). UIP was derived from the works of Keynes, where the fundamental principles was established by Tsiang (1958). The interest rate parity is a non-arbitrage condition, indicating an equilibrium where holding two similar assets of different currency of denomination will yield the same profit, making sure no arbitrage profits could be made. If one of the assets is denominated in a currency with a high interest rate, the parity condition ensures that the expected gain from investing in the asset will be offset by a depreciation of the assets currency, giving the same yield between any two assets. Looking at UIP, it describes the relationship between the change in the spot exchange rate and the interest rate differential. Where, the change in the spot exchange rate is defined as the change between time period t and $t + k$. The uncovered interest parity as

opposed to covered interest parity do not rely on forward exchange contracts. Rather, the UIP theory rest on the assumption of rational expectations, meaning that the spot exchange rate today should be an unbiased predictor of the future spot exchange rate. This is described in the name of the theory, uncovered meaning that no covered position using forward contracts is being used (Krugman, Obstfeld & Melitz, 2014).

Previous research has tested the theory by the use of interest rates with a maturity less than 12 month, with a sample period of approximately 20 years (1970 – 1990) and using larger economies where the U.S. is generally included. These studies have commonly rejected the theory, see McCallum (1994), Froot and Thaler (1990), Meredith and Chinn (2004), meaning that the differential of the short-term interest rates fails to explain the change in the spot exchange rate. In a large study by Froot and Thaler, they found that the average β estimate among 75 published estimates was equal to -0.88. The deviation was attributed to overshooting of the expected inflation. The theory of UIP implies that the β estimates should be equal to one, meaning that the result found by Froot and Thaler shows and inverse relationship of the theory. In recent year the validity of the UIP theory has seen new light, as research using longer sample periods, going beyond 20 years by using sample periods of up to 200 years, and interest rates with longer maturities has been able to confirm the theory, see Meredith and Chinn (2004), Alexius (1998) and Lothian and Wu (2011). Only a few studies have been conducted to investigate if UIP hold under economic fluctuations and crises. Flood and Rose (2002) investigated the behavior of UIP under economic fluctuations using both large and small open economies under the crisis in the 1990's. They concluded that UIP held better than previous research had estimated.

The purpose of this thesis is to test the uncovered interest parity (UIP), its robustness and functioning over the course of different time periods with varying economic climates. To test the strength of UIP we have structured a short-horizon test and a long-horizon test. The short-horizon test is aimed at testing whether the UIP holds for the interbank offering rates (IBOR's) between the United States and the Scandinavian countries. The long-horizon test is structured to test if the UIP holds over the long run between the bonds yield to maturity for the above-mentioned countries. The short- and long-horizon test is conducted to establish whether the UIP hold better in the short or long-run. The Scandinavian countries are included to test the robustness of the UIP theory for quite similar small open countries, a contrast to previous research who mostly conduct the testing

using larger economies. Further, as mentioned, a few studies have tested UIP over economic fluctuations and economic downturns. Seeing as the crisis of 2007 had a great impact on the global economy and affected both interest rates and exchange rate movements, we extend this paper to also test how the crisis influenced the uncovered interest parity. The data in this paper is collected from Thomson Reuters DataStream, and the Federal Reserve Bank of St. Louis. We obtain the interbank offering rates of 3-month maturity, as well as the yield to maturity for the government 10-year benchmark bonds. Daily spot exchange rate data is gathered for the short-horizon test, and monthly data for the spot exchange rate for the long-horizon test. The exchange rate is expressed as the price of one unit of foreign currency in units of domestic currency. We thereafter utilize regression analysis, OLS, to regress the logarithmic interest differential on the realized change in the spot exchange rate over the three time periods: pre-crisis (2000-2006), crisis (2007-2011), and post-crisis (2012-2018). According to the theory the slope parameter should equal one, and the intercept should equal zero. We therefore establish three null hypotheses, as a slope parameter that is not equal to one could still explain the dependent variable. We utilize t-tests to test these hypotheses. For the purpose of testing for larger interest differentials, as assumed to be caused by the crisis, we establish an extreme sampling. Here we use three different percentiles of the absolute realizations of the interest rate differential, with the assumption that a higher interest differential provides better support for the theory.

Our findings suggest that UIP holds better during economic fluctuations, as the result for the crisis period is well in line with the theory. This is as greater economic fluctuations and volatility strengthens the predictive power of UIP, as larger interest differentials have better predictive power for future spot exchange rather than small differentials. The results using the 3-month IBOR's proved to explain the theory better than using the yield to maturity for the 10-year benchmark bonds. As explained by Alexius (1998) the use of yield to maturity in the regression of UIP comes with some limitations, it creates a bias of the slope parameter to one. The pre- and post-crisis period did not support the theory as well, where most of the estimates could be rejected to be equal to one.

The thesis is structured as follows. In section 2 we describe the theory underlying UIP. Section 3 present the method used. Section 4 describes the data. In section 5 we present the results we obtained. Section 6 concludes.

2. Theoretical Framework

For this part of the thesis we will look into the theory of the interest rate parity condition, more specifically the uncovered interest rate parity. In order to do so, we must first define the theory underlying the interest rate parity and its real-life application. The theory of interest rate parity is based on the assumption of a non-arbitrage situation, meaning two similar assets in different countries should yield the same profit when denoted in the same currency. If this is true, we have an equilibrium between the two markets. If the equilibrium is violated, the exchange rates must remedy the situations by a depreciation of the currency yielding the relatively larger profit. There exists two different versions of non-arbitrage opportunities, the first of these being the covered interest parity (CIP) and the second one the uncovered interest parity (UIP), of which the latter is the focus of this thesis. CIP and UIP are in theory quite similar, though there exists one main difference. Where CIP and UIP deviates from one another is with the inclusion of forward exchange rate contracts in CIP, where UIP assumes that the current spot exchange rate is an unbiased predictor of the future spot exchange rate by the implementation of rational expectations. Hence, if we are in a non-arbitrage opportunity where an investor can take a covered position by using forward exchange rate contracts, indicating that the investor will prepare for a conversion of his foreign assets at time t into domestic assets at time $t + k$, then we have the covered interest rate parity (Isard, 1991). Assuming the same situation, under the uncovered interest parity the investor would be in an uncovered position, as the current spot exchange rate is an unbiased predictor of the future spot exchange rate. The following paragraphs will further research the justifications, theory and math behind the application of UIP in our model, as well as the regression model in use.

2.1 Covered Interest Parity

To introduce uncovered interest parity, it is convenient to start with the introduction of covered interest parity, CIP. The covered interest parity relates the interest differential to the difference between spot and forward exchange rates. In equilibrium, this will give us a non-arbitrage opportunity when using forward contracts. For example, assuming a 6-month interest rate where we have two markets, A and B. A has an interest rate of 11 percent and B has an interest rate of three percent. The intestate rate differential is eight percentage points, thus the forward contract of converting A's currency into B's currency must have an eight percent discount for the CIP to hold. If this is not the case, investors

will borrow at the low interest rate (B), convert in to A's currency and investing in the higher interest rate using A's forward contracts. If these contracts are bought with a four percent discount, there exists a four percent risk-less arbitrage opportunity, to prevent this the currency of country A must depreciate with four percent. The relationship between the forward exchange rate contracts, spot exchange rate and interest rate differential for covered interest parity is described as:

$$F_{t,t+k}/S_t = I_{t,k} \,/\, I^*_{t,k} \tag{1}$$

where S_t is defined as the price of foreign currency in units of the domestic currency at time period t. $F_{t,t+k}$ is a forward contract of the spot exchange rate expiring k periods in the future. $I_{t,k}$ is defined as the domestic one plus k-period rate, and $I^*_{t,k}$ is the rate for the foreign asset (Meredith & Chinn, 2004). Taking the logarithms, symbolized by lowercase letters, of equation (1) results in the following expression from the logarithm laws:

$$f_{t,t+k} - s_t = (i_{t,k} - i^*_{t,k}) \tag{2}$$

Equation (2) states that the two sides must be equal, if the two are not equal, arbitrage could be made, as it ignores the investors' preferences (McCallum, 1994). However, the foreign assets can be perceived as riskier than domestic assets, therefore risk-averse investors will demand a risk premium to be compensated for taking on the extra risk. The risk premium will enable the forward rate contract on S to differ from the expected spot exchange rate by a risk premium. One can therefore define the expected spot exchange rate as $s^e_{t,t+k}$ at time period $t+k$ formed at t, and $RP_{t,t+k}$ the risk premium formed at time t (Meredith & Chinn, 2004). Giving the following expression:

$$f_{t,t+k} = s^e_{t,t+k} - RP_{t,t+k} \tag{3}$$

By substituting equation (3) into equation (2), the expected change in the exchange rate from period t to period $t+k$ is expressed as a function of the interest rate differential and the risk premium:

$$\Delta s^e_{t,t+k} = \left(i_{t,k} - i^*_{t,k}\right) - RP_{t,t+k} \tag{4}$$

2.2 Uncovered Interest Parity

As we move from one non-arbitrage theory to another, equation (4) do produce a reliable approximation of the UIP theory assuming investors are risk-neutral, and with the risk premium equal to zero. In this equation, the expected spot exchange rate is equal to the current interest rate differential. However, as market expectations of the future exchange rate movements are not easily available, equation (4) cannot directly be used to test UIP. In order to test the theory, UIP is most often tested jointly with the assumption of rational expectations in the exchange market (Isard, 1991). It is therefore assumed that the future realizations of s_{t+k}will equal the value that is expected at time t plus a white noise error term $\xi_{t,t+k}$.The error term is assumed to be uncorrelated with all the information known at time t, and the following expression is obtained:

$$s_{t+k} = s_{t,t+k}^{re} + \xi_{t,t+k} \tag{5}$$

where the variable $s_{t,t+k}^{re}$ is defined as the rational expectations of the exchange rate at time $t+k$, formed in time t. To get an expression for the realized change in the exchange rate from t to $t+k$ determined by the interest rate differential, the risk premium and an error term, one can substitute equation (5) into equation (4). Resulting in the following expression (Meredith & Chinn, 2004):

$$\Delta s_{t,t+k} = \left(i_{t,k} - i_{t,k}^{*}\right) - RP_{t,t+k} + \varepsilon_{t,t+k} \tag{6}$$

For the purpose of testing UIP, utilizing regression analysis, the equation proposed by Meredith and Chinn (2004) is most commonly used:

$$\Delta s_{t,t+k} = \alpha + \beta\left(i_{t,k} - i_{t,k}^{*}\right) + \varepsilon_{t,t+k} \tag{7}$$

From the assumptions of risk-neutrality and rational expectations, the change in the spot exchange from time t to $t+k$ is inferred by the interest differential and the risk-premium at period t. From this, the theory implies that the slope parameter, β, should be equal to one. Results where the β coefficient deviates from one can be realized from two phenomena: the deviation from risk-neutrality and/or rational expectations and a correlation between these deviations and the interest rate differential (Meredith & Chinn, 2004). An alternative test that is commonly conducted is to test if the constant term, α, is equal to zero. Deviations from zero can represent a constant risk premium, Froot and

Thaler (1990) argue that expectational errors cause a bias of the interest differential, where the risk premium is constant. In this line of theory, the link of inflation and interest rates are assumed to cause expectational errors. As most of the time inflation is restricted in a controlled range. In these periods, increases in the expected inflation will overpredict and overshoot the previous periods realized inflation. Increases in the expected inflation will then be followed by increases in the nominal interest rate and the expected depreciation of the currency. As a result, the β estimates will be less than one (Mussa, 1979). During periods when inflation builds up and increases, and the nominal interest rates increase to be very large, has resulted in β estimates that is positive and, in a range, close to one. As we know that inflation builds up in the wake of a financial crisis and rises steadily during the crisis, this will then support the hypothesis from of Froot and Thaler (1990), where the overshooting problem becomes less problematic. As, the expected increase in inflation would be met by the actual inflation and the increase in the nominal interest rates (Gärtner, 2016).

Many studies have been made on UIP and the unbiasedness hypothesis that β equals 1, where these studies have failed to confirm the unbiasedness of the slope parameter. Studies have shown that the beta coefficient is frequently reported to be less than one. A large meta-survey by Froot and Thaler (1990) found the average β to be -0.88, across 75 published estimates. It has been argued that by manipulating the short-term interest rates when conducting a monetary policy can produce these negative estimates. Further, the movements of the exchange rates are hard to predict in the short run, therefore the prediction result increases as we move further into the future (McCallum, 1994). A negative β estimate implies that, if the U.S. interest rate is one percentage point higher than the foreign interest rate, we will see the dollar appreciate by one percent per year.

3. Method

3.1 Uncovered Interest Parity Estimation

3.1.1 OLS

In the process of analyzing UIP and how it interacts with the interbank offering rates and yield to maturity under economic fluctuations, we will utilize ordinary least squares (OLS). OLS produces strong and reliable estimates, as long as the model satisfies the underlying

assumptions, for example stationarity, no autocorrelation, homoscedasticity and so on (Gujarati & Porter, 2009).

To test UIP, regression equation (7) and (8) will be used, where the dependent variable is equal to the logarithm of the change in the spot exchange rate between t and $t+k$, where k is the three month lag for the regression of the interbank offering rates, and one year lag for the regression using the bonds yield to maturity (Meredith & Chinn, 2004). Previous research utilized similar methods, see Meredith and Chinn (2004), Alexius (1998), implementing bonds with a 10-year lag. This was not optimum for this paper as our sampling period of 20 years is relatively small. These lags are selected as they produce regression outputs in line with our theoretical hypotheses, and as longer lags would require a larger sample period.

Following Meredith and Chinn (2004), the independent variable is the interest rate differentials between the selected countries. For the short-horizon test, the interest rates are expressed as: $1+i$, where i is expressed in percentage form. The independent variable is then equal to the natural logarithm of the difference between the domestic and foreign interest rate, $\left(i_{t,k} - i^*_{t,k}\right)$, where $i_{t,k}$ is defined as the domestic interest rate and $i^*_{t,k}$ as the foreign interest rate.

For the long-horizon test, the variable i is defined as the holding period return for the investment between t and $t+k$, using the yield to maturity as the interest rate. If the yield to maturity is y_t, then i will equal $(1+y_{t,k})^k - 1$, where k is the holding period (Alexius, 1998). After this transformation we can obtain the logarithmic interest rate differential between the domestic and foreign country, once again $i_{t,k}$ is the domestic interest rate and $i^*_{t,k}$ the foreign interest rate.

3.1.2 Panel Data Regression

We will also conduct a panel data regression. A panel data regression combines the cross-sectional and time-series properties of regression analysis. From this combination, the panel data regression is able to produce more efficiency, as more degrees of freedom are obtained, resulting in a more informative regression. Therefore, the panel regression will better measure the effects for UIP, rather than a pure cross-sectional or time-series regression (Gujarati & Porter, 2009).

We will utilize a fixed-effect panel regression (FEM), also called fixed-effect least-squares dummy variable (LSDV) model, as used by Meredith and Chinn (2004). The fixed-effect model was chosen as this proved to be the preferred model when conducting the Hausman and the F-test. This regression allows for heterogeneity among the subjects, as the countries will have their own intercept value. The intercept value is allowed to vary across the individual subjects; however, the individual countries intercept will not vary, meaning that they are time-invariant. In order to make the intercepts to vary across the subjects, we introduce the differential dummy technique. Where, each intercept is assigned a dummy variable. Following Gujarati and Porter (2009), we get the following regression equation for the fixed- effect model:

$$\Delta s_{t,t+k} = \alpha_1 + \alpha_2 D_{2i} + \alpha_3 D_{3i} + \alpha_4 D_{4i} + \beta\left(i_{t,k} - i^*_{t,k}\right) + \varepsilon_{t,t+k} \qquad (8)$$

In the regression we only introduce 3 dummy variables, as introducing the same number of dummy variables as subjects will result in a dummy-variable trap. In the equation above, we define Denmark as the base for the regression, hence α_1. Therefore, α_2, α_3, α_4 is equal to the intercept for Iceland, Norway and Sweden, respectively. Where, D_{2i} is one for Iceland and zero otherwise, the same goes for the dummies of Norway and Sweden (Gujarat & Porter, 2009). In this paper we test the jointly significance of all the effects and the jointly significance of the cross-section effects.

3.2 Testing the assumptions of OLS

3.2.1 Stationarity

One assumption of OLS is that the process has to be stationary. Stationarity can be defined as a process whose mean and variance are constant over time, and the value of the covariance between the two time periods depends only on the distance or gap or lag between the two time periods and not the actual time at which the covariance is computed. This means that the mean, variance and covariance are time invariant, and exhibit mean reversion, they stay the same no matter at what point they are measured. On the other hand, if the process is said to be non-stationary the mean, variance or both are time-varying. A non-stationary process can only be used to draw inferences on the time period under consideration, and not generalize it to other time periods (Gujarati & Porter, 2009). One reason for a non-stationary process is due to the presence of a unit root. A unit root stochastic process takes place when a root of the characteristic polynomial is equal to one

or is inside the unit root circle. As OLS requires the time-series sample to be stationary, the variables in the regressions have to be tested for any unit roots. In order to detect any unit roots we applied the Augmented Dickey-Fuller (ADF) unit root test (Gujarati & Porter, 2009). The null hypothesis for the augmented Dickey-Fuller unit root test is that the process is non-stationary, and a unit root is present. We will test for unit roots both with the intercept and without the intercept. Testing without the intercept is a more powerful testing procedure if the average value of the variable is zero, which can be assumed for the independent variable. The testing equation with the intercept is:

$$\Delta Y_{t-1} = \alpha + \delta Y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta Y_{t-i} + \varepsilon_t \quad (9)$$

and, the equation without the intercept is:

$$\Delta Y_{t-1} = \delta Y_{t-1} \sum_{i=1}^{p} \beta_i \Delta Y_{t-i} + \varepsilon_t \quad (10)$$

Where, we test the delta variable to see if it is equal to zero using the Dickey-Fuller t-statistic. Regressing a variable that contains a unit root on the dependent variable can result in a spurious regression. To avoid a spurious regression, one remedy is to take the first difference, if the process $I(d)$ contains a unit root taking d first differences will make the process stationary.

3.2.2 Panel Unit Root Test

Testing for a panel unit root has more powerful properties than testing for a unit root on each separate cross-section or times-series alone (Levin, Lin & Chu, 2002). It has been shown that individual unit root test has limited power when it comes to finite samples, there is a bias towards the null hypothesis that the variable is nonstationary. By combining the p-values from the individual unit root tests from each cross-section, we create a more powerful unit root test for the panel regression. We will utilize the individual-Fisher ADF test which combines the individual p-values, and do not allow that some groups have a unit root and others do not. The combined p-value is calculated using the following equation (Levin, Lin & Chu, 2002):

$$P = -2 \sum_{i=1}^{N} \ln (p_i) \quad (11)$$

The null hypothesis for the individual-Fisher ADF test is therefore: presence of unit root, non-stationary, for all the subjects in the panel. Where, we once again will test for unit roots both with and without the intercept, as we expect a more powerful result by excluding the intercept.

3.2.3 Testing the OLS Assumptions

After testing for stationarity, one can start considering OLS. As OLS comes with some underlying assumptions, we also have to test the process for these underlying assumptions, such as no autocorrelation and no heteroscedasticity. For all of the regressions, the Durbin-Watson d statistic is close to zero, indicating the presence of positive autocorrelation. Autocorrelation of a random process shows the degree of correlation between values of the process at different time points, this can be shown as a function of the two times or of the differences in time (Gujarati & Porter, 2009). Formally, we can define the autocorrelation as:

$$cov(x_i, x_j | u_i, u_j) = E(u_i, u_j) \neq 0 \tag{12}$$

Autocorrelation is a violation to the OLS assumptions, making the estimates inefficient and no longer to have minimum variance. Additionally, we conducted a Breush-Pagan heteroscedasticity test, where we could conclude that heteroscedasticity was present. As a result, the estimates are no longer best linear unbiased estimators (BLUE). This violation makes the usual test statistics, such as t, F and χ^2, to no longer be reliable (Gujarati & Porter, 2009). To correct the residuals from this violation we will utilize the heteroscedasticity and autocorrelation correction method, HAC Newey and West. This method corrects the standard errors for both autocorrelation and heteroscedasticity, making the estimates obtained robust and reliable.

3.3 Testing Uncovered Interest Parity

After establishing the regression, we can start conducting different tests in order to evaluate the robustness and how the uncovered interest parity holds over the different time periods. Simple t-test are conducted to test the estimates produced by the regressions, in order to evaluate the theory underlying UIP. Then, an extreme sampling using the absolute realization of the interest rate differentials is used, in order to confirm the relationship between the interest rate differentials and the predictor power of the future spot exchange

rates. Finally, in order to test the theory and its strength over time a rolling regression is performed.

3.3.1 t-test

In order to evaluate the theory of UIP and to test how the estimates hold with it, simple t-tests are conducted to test the estimates produced. According to the theory underlying UIP, the β estimates should equal one. In order to test whether β equals one, a null hypothesis that $\beta = 1$ is established.

If we cannot reject the null hypothesis, this means that the interest differential is related to the change in the spot exchange rate as stated by the theory. However, this is not the full picture, an estimate $\beta \neq 0$ can still make the relationship between the interest differential and spot exchange rate to hold. Therefore, another set of hypotheses is set up, with the null hypothesis that $\beta = 0$.

A final test is also made to test whether $\alpha = 0$ or not, a deviation from zero can be an indication of a constant risk premium. All of the t-tests are performed to test the estimates produced from regression equation (7), and the fixed-effect panel regression equation (8).

3.3.2 Rolling Regression

We also implement a rolling regression in order to realize how the size of the sampling periods affect the consistency of the β estimates, as shown by Lothian and Wu (2011). For this purpose, the end date of December 2018 is anchored as a constant, thereafter consecutive regressions are performed where the starting period is progressively moved forward throughout the whole sample period, resulting in a stepwise lower sample size. For the interbank offering rate, the rolling regression is performed throughout the sample period 2002 to 2018, and throughout the sample period of 2000 to 2018 for the bond yields. A time-invariant estimate will produce a line that is perfectly horizontal, whereas if the estimate change over time the line will deviate and produce increasing fluctuations (Lothian & Wu, 2011).

3.3.3 Extreme Sampling

We will also investigate the behavior of the estimates conditional on the absolute realization of a value being large, where different absolute realization of the interest differentials are utilized. This is done with the assumption that UIP will hold better at

higher absolute values of the interest differentials. This due to an increase in the magnitude of the signal (the size of the effect) corresponding with the interest differential, will improve the accuracy of the expectations of the exchange rate in the market, and what it will be. This can be the result of a measurement error, indicating a larger signal to noise ratio resulting in a more accurate prediction in the exchange rate movements (Lothian & Wu, 2011). Following Lothian and Wu (2011), we construct the following equation:

$$\Delta s_{t,t+k} = \alpha + \beta^{S}\left(i_{t,k} - i^{*}_{t,k}\right)I_{t\epsilon S} + \beta^{L}\left(i_{t,k} - i^{*}_{t,k}\right)I_{t\epsilon L} + \varepsilon_{t,t+k} \qquad (13)$$

Where *S* and *L* indicates the magnitude of the absolute realization, *L* indicates values larger than the absolute value, and *S* indicates values smaller than the absolute value. $I_{t\epsilon S}$ is applied as a dummy variable that equals one if the interest differential is smaller than the absolute realization, and zero otherwise. Consequently, $I_{t\epsilon L}$ is a dummy that equals one if the interest differential is larger than the absolute realization, and a zero otherwise (Lothian, 2011). In order to test the assumption stated above the 50, 70, and 90 percentiles of the interest differential are obtained to serve as the threshold for the testing. Previous research has utilized the 90 to 99 percentiles. As we wish to observe the broad movements, we selected percentiles with larger differences. So, $I_{t\epsilon S}$ equals one if the absolute value of the interest differential is smaller than the 50, 70, or 90 percentile value of the interest differential, the opposite holds for $I_{t\epsilon L}$. Further it is also assumed that the β^{S} estimates will decline and be close to zero, whereas the β^{L} estimates will increase and stay positive as progressively higher percentiles are being used (Lothian & Wu, 2011).

4. Data

Previous research has commonly rejected UIP, where most of the studies have used interest rates with maturities shorter than 12 months based on larger economies. This paper will counter the majority of the previous research and base this study on smaller economies. The U.S. is chosen to serve as the base, as this is the largest economy in the world with the power to influence other economies. Further, the financial crisis that started in the U.S. in September 2007 paved the way for a new Great Depression and started with the bankruptcy of the investment bank of Lehman Brothers. To enable the testing of the UIP for small open economies, the Scandinavian countries are incorporated in the testing. The countries of Denmark, Sweden and Norway are similar in size, as measured by their GDP (The World Bank, 2018). Compared to the rest of the Scandinavian countries and the U.S.,

Iceland is the smallest economy in the sample. The Scandinavian countries were hit by the 2007 crisis and later the European debt crisis to a varying degree, where Iceland went into a deep recession when three of its largest banks went under in 2008.

4.1 Data Summary

Regression equations (7) and (8) states that the change in the spot exchange rate from t to $t + k$ is a result of period t interest rate differential. For this, we need the currencies of the countries under consideration. The exchange rates are expressed as one unit of foreign currency in units of domestic currency. The currencies used is the United States Dollars, Danish Krone, Icelandic Krona, Norwegian Krone and the Swedish Krona.

Further, we need the interest rates for the individual countries. The UIP theory states that the interest rates used must be risk-free interest rates. This is for UIP to hold as an unbiased predictor of the future spot exchange rates. We therefore have to assume that the investors are risk-neutral and the presence of a risk-premium that is equal to zero. For a risk-neutral investor to predict the future spot exchange rate from the interest differentials, there can be no errors in this prediction. For the error of the prediction to be zero the risk-free interest rates are used, which will reduce the risk-premium to zero. If the risk-premium is equal to zero, the interest differential will serve as an unbiased predictor of the future spot exchange rate (McCallum, 1994). A risk-free interest rate is the rate of return on a theoretical investment that do not possess any risk, hence, the risk-free interest rate is the rate of return an investor can be expected to yield on a truly risk-free investment. As no investment is truly risk-free a number of proxies are used to represent the risk-free rate. The most commonly used proxy for the risk-free rate is the government benchmark bonds, a security backed by the government where the risk of the government to default on its obligations is minimal (Bodie, Kane & Marcus, 2014). Another commonly used proxy is the Interbank Offering Rates, these are rates that the largest banks charge among themselves for uncollateralized short-term loans, where the London Interbank Offering Rate (LIBOR) is the most common proxy.

As this paper aims to test the UIP both at a short- and long-horizon under different economic climates, the IBOR's will be used as the risk-free rate in this paper to test the short-horizon validity of the UIP. The IBOR's have been used for testing the theory in previous studies, see for example Meredith and Chinn (2004). The long-horizon test will

use the yield to maturity of government 10-year benchmark bonds as a proxy for the risk-free rate, as used by Alexius (1998) and Meredith and Chinn (2004). The currencies and interest rates used are summarized in table 1.

Table 1. Data summary

Country	Currency	IBOR	Bonds
USA	USD	USD LIBOR	US T-NOTE
Denmark	DKK	CIBOR	DKGV T-BOND
Iceland	ISK	REIBOR	ISGV T-BOND
Norway	NOK	NIBOR	NOGV T-BOND
Sweden	SEK	STIBOR	SEGV T-BOND

The maturity chosen for the IBOR rates is three months. The 3-month maturity IBOR's are frequently quoted and data are easily available. The benchmark 10-year government bonds are chosen for their longer maturities, and risk-free characteristics that they represent in the testing of the long-horizon. In the regression of UIP the USD LIBOR and US10Y will represent the domestic interest rate in equation (7) and (8).

The data for the short-horizon test is gathered from Thomson Reuters Datastream, where we obtain the spot exchange rate and the IBOR rates. Thomson Reuters Datastream continually update and gather data from the individual countries' central banks. We use daily data to fully construct a short-term, which will reflect the movements of the market. The data for the long-horizon test is gathered from the Federal Reserve Bank of St. Louis and Thomson Reuters DataStream. Where, we use monthly observation, specifically end of the month quotes. End of the month data is used as the observations would be too vast to be analyzed if daily data were to be used for the long-horizon test. Some of the interest rates gathered were negative, for example STIBOR, and as one cannot take the logarithm of a negative value, this posed a problem for us. This problem was countered by the fact that as the variables in the calculation of the interest rate differential is expressed as one plus the interest rate, where the interest rate is expressed in decimal form, we overcame this problem.

4.1.2 Descriptive Statistics

Below we find the descriptive statistic for the data. As can be observed from the table, the mean value for the dependent variable is mostly negative, in seven out of ten cases. The mean for the independent variable has more positive values. The maximum values are small and close to zero, where the values for the independent variables for Denmark in the short-horizon and the independent variable for the panel data in the long-horizon stands out, with values around five. As for the minimum values, we also observe values close to zero, where the value for the dependent variable in the long-horizon test for the panel stands out with a value of approximately -1.9.

Table 2. Descriptive statistics

Descriptive Statistics										
			Short-horizon							
	Denmark		Iceland		Norway		Sweden		Panel	
	Dep	Indep	Dep	Indep	Dep	Indep	Dep	Indep	Dep	Indep
Mean	-0.0014	0.0008	-0.0032	-0.0595	0.0023	-0.0099	0.0007	0.0007	0.0023	0.0023
Max	0.1526	0.0306	0.6243	-0.0202	0.1299	0.0236	0.2084	0.0309	0.6243	0.0309
Min	-0.3374	-0.0381	-0.5243	-0.1581	-0.2052	-0.0549	-0.2729	-0.0271	-0.5243	-0.1581
Std.dev	0.0574	0.0139	0.0574	0.0257	0.0480	0.0177	0.0578	0.0165	0.0689	0.0313
			Long-horizon							
	Dep	Indep	Dep	Indep	Dep	Indep	Dep	Indep	Dep	Indep
Mean	-0.0633	0.2427	-0.0041	-0.0879	-0.0720	-0.0701	-0.0743	0.1130	-0.0699	0.0695
Max	0.2342	5.1459	0.8531	0.6766	0.2755	0.5757	0.2356	2.8257	0.2755	5.1459
Min	-0.5625	-0.5625	-0.8464	-0.8464	-0.6620	-0.6620	-0.8033	-0.8033	-1.9331	-0.8464
Std.dev	0.3509	0.7327	0.2627	0.2817	0.3532	0.2539	0.3470	0.6095	0.3504	0.5296

4.1.2 Criticism of the risk-free rate

The risk-free rates used before the establishment of the interbank offering rates were the rates for short-term securities, such as the U.S. 3-month Treasury bills. Critic was raised for using the treasury bills as a risk-free rate as they are influenced by factors other than the pricing of financial securities, such as the government funding needs and debt (Hull & White, 2013). As the criticism grew stronger the interbank offering rates became used as a proxy for the risk-free rate. These rates are determined from the unsecured loans charged among the major banks within an economy and reflect the confidence and strength of the banks. When the financial crisis hit the global economy in 2007, the volumes of unsecured loans between the banks decreased drastically and came to affect the IBOR's. This reduced funding and liquidity, reflecting both counterparty risk and uncertainty of the banks determining the benchmark rate. Higher rates came to be charged among the banks as the

trust and confidence decreased, which limited the rates to serve as a risk-free rate. The crisis did not limit the default risk only to banks, countries such as Iceland had a deep sovereign crisis. Criticism of the interbank offering rates is not only limited to the financial crisis. In 2012 it was shown that some international banks had intentionally manipulated the benchmark rates, from as early as 2005. These banks hade misleadingly reported their own interest rates and other's interest rate, to hide their weak financial position (Granlund & Rehnby, 2018). Efforts has been made to reestablish the trust of the IBOR's to serve as a risk-free rate (Persson, 2012). For the purpose of testing the uncovered interest parity we will ignore the recent criticism and use the stated interbank offering rates and the yield to maturity for the government 10-year benchmark bonds as the risk-free rate.

5. Empirical Results and Analysis

5.1 Short-horizon

We begin by looking at the results from the regression of the short-horizon test, using the interbank offering rates (IBOR's).

We started off by testing the robustness of the short-horizon test, see appendix A. In order to determine which panel regression to be utilize, we performed a Hausman test and an F-test. The null hypothesis of the Hausman test can be rejected, indicating that there exists a correlation between the unobserved random effect and the estimates, thus the fixed effect is the preferred one. Further, we can also reject the null hypothesis for the F-test at the 1 percent significance level, and we once again favor the fixed-effect panel. The fixed-effect is thereby proven to be more efficient in producing consistent estimators within our data set.

The null hypothesis for the augmented Dickey-Fuller unit root test could not be rejected for the dependent variables, meaning that the variables are stationary as no unit root is present. For the independent variables we cannot reject the null hypothesis, so we can conclude that the independent variables are nonstationary as a unit root is present. By excluding the intercept, the testing becomes more powerful as the null hypothesis can now be rejected for some of the samples at the five percent significance level.

Further, to strengthen the unit root testing, the individual-Fisher ADF test is implemented. By including the intercept, we cannot reject the null hypothesis, meaning that we have a

common unit root for the panel regression, and also individual unit roots. We conducted the same individual-Fisher ADF test and excluded the intercept. By excluding the intercept, we can reject the null hypothesis at the 5 percent significance level. The individual-ADF test do not allow some groups to have a unit root and other do not, from this we can generalize the result and say that the independent variable is stationary, even for the OLS time-series regression (Levin, Lin & Chu, 2002). This as, the panel unit root testing is a much more powerful tool to test for a unit root, and the testing power is further strengthened by excluding the intercept from the regression. We exclude the intercept since the descriptive statistics shows that the average value of the variables is approximately zero. The common p-value further reinforces the predictive power of the test; therefore, the panel unit root test is more reliable. So, we can reject the null hypothesis that the process contains a unit root both for the OLS regression and the fixed-effect panel. As the process is stationary, we use equation (7) and (8) to test UIP. The results for the pre-crisis period is presented in table 3.

Table 3. Regression result for pre-crisis period.

PRE-CRISIS 2002 - 2006	$\widehat{\boldsymbol{\alpha}}$	$\widehat{\boldsymbol{\beta}}$	$\widehat{\boldsymbol{\beta}} = \mathbf{1}$	$\boldsymbol{R^2}$	**N**
CIBOR (Denmark)	0.023710*** (0.004028)	– 1.143488*** (0.239679)	***	0.132395	829
REIBOR (Iceland)	0.019605 (0.047089)	– 0.048956 (0.694932)		0.000013	829
NIBOR (Norway)	0.011045** (0.004352)	– 0.266439* (0.136066)	***	0.019797	829
STIBOR (Sweden)	0.023228*** (0.004431)	– 0.821387*** (0.188740)	***	0.099084	829
Panel (FEM)	0.011661*** (0.001745)	-0.538089*** (0.079120)	***	0.015763	829

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 3-month interbank offering rates (IBOR). The values in parentheses denotes the Newey and West standard errors. The sample period is 8/15/2002 to 12/28/2006. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that $\beta = 0$ and $\beta = 1$. The last row reports the estimates for the fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates for the pre-crisis period are all negative, with an average of -0.56, in line with the average estimates found by Froot and Thaler (1990). For REIBOR, none of the

null hypotheses can be rejected. The null hypothesis that β is equal to one can be rejected at the 1 percent significance level for CIBOR, NIBOR, STIBOR and the fixed-effect panel. Further, the null hypothesis that β is equal to zero can be rejected at the 1 percent significance level for CIBOR, STIBOR and the fixed-effect panel, and at the 5 percent significance level for NIBOR. Froot and Thaler (1990) attributed the deviation of UIP from expectational errors, from the link between inflation and interest rates. Periods with low inflation rates typically overshoot the previous periods inflation as the expected inflation increases. This would increase the nominal interest rates and the expected depreciation of the currency, hence β estimates less than one, as can be seen here. The negative β estimates implies a negative relationship between the change in the spot rate and the interest rate differential, where the largest negative value for CIBOR implies that a 1 percent higher interest rate in the U.S. will induce a 1.14% appreciation of the Danish krone against the US dollar. We also test if the intercept, α, is equal to zero as a value that is not equal to zero may indicate a constant risk-premium. The null hypothesis that α is equal to zero can be rejected for CIBOR, STIBOR and the fixed-effect panel at the 1 percent significance level, and at the 5 percent significance level for NIBOR. Studies has been made to quantify the risk premium and to evaluate its influence on validity of UIP. As this paper do not aim to evaluate the risk premium any further, we will ignore the fact that it is different from zero. The next test is for the crisis period, the results from the regression is presented in table 4.

Table 4. Regression results for the crisis period.

CRISIS 2007 - 2011	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\beta} = 1$	R^2	**N**
CIBOR (Denmark)	0.013305*** (0.003917)	1.090868*** (0.325236)		0.050665	1174
REIBOR (Iceland)	0.065699*** (0.023658)	1.125878*** (0.357134)		0.126819	1174
NIBOR (Norway)	0.039615*** (0.005577)	1.891834*** (0.380912)	**	0.111152	1174
STIBOR (Sweden)	0.007242 (0.004963)	0.778368*** (0.299837)		0.019862	1174
Panel (FEM)	0.029684*** (0.001929)	1.163030*** (0.0551)	***	0.107815	1174

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 3-month interbank offering rates (IBOR). The values in parentheses denotes the Newey and West standard errors. The sample period is 1/03/2007 to 12/28/2011. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that $\beta = 0$ and $\beta = 1$. The last row reports the estimates for the fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates are now positive and close to one. The null hypothesis that β is equal to one cannot be rejected for CIBOR, REIBOR and STIBOR. Hence, we reject that β is one for NIBOR and the fixed-effect panel. We also test if the β estimates are equal to zero, as an β estimate that is different from one may still influence the dependent variable. The test shows that we can reject the null hypothesis for all the IBOR's and the fixed-effect panel at the 1 percent significance level. This result can be attributed to the higher inflation rates that arose during the crisis period. It has been shown that as the inflation rate increases at high levels, the overshooting problem becomes less severe. The nominal interest rates would therefore have to rise at even greater magnitudes, and the expected depreciation is more easily predicted, as supported by Froot and Thaler (1990). The intercept, α, is close to zero for all the IBOR rates and the fixed-effect panel, and we test to see if it is equal to zero. The null hypothesis that, α, is equal to zero cannot be rejected for STIBOR, but can be rejected for the other IBOR rates and the fixed-effect panel. Supporting the assumption of a constant risk premium, that is associated with the higher inflation of the period. Overall, we can see that the crisis period produces estimates more in line with the theory of the uncovered interest parity. The β estimates for the crisis period correspond well with

the theory as they are all close to one, and some are even statistically equal to one, compared to the pre-crisis period where we found an average β of -0.56. The estimates for α remained at a value close to zero as we moved from the pre-crisis period to the crisis period. Lastly, table 5 present the results for the post-crisis period.

Table 5. Regression results for the post-crisis period.

POST-CRISIS 2012 - 2018	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\beta} = 1$	R^2	**N**
CIBOR (Denmark)	– 0,007997** (0,003400)	0,314441 (0,261794)	***	0,005476	1614
REIBOR (Iceland)	– 0,049931*** (0,014590)	– 1,040047*** (0,282845)	***	0,074638	1614
NIBOR (Norway)	– 0,009067*** (0,003447)	0,136828 (0,233167)		0,001128	1846
STIBOR (Sweden)	– 0,009127*** (0,003115)	– 0,156308 (0,195269)	***	0,002466	1614
Panel (FEM)	-0,006075*** (0,000742)	-0,175709*** (0,047424)	***	0,012471	1614

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 3-month interbank offering rates (IBOR). The values in parentheses denotes the Newey and West standard errors. The sample period is 1/03/2012 to 12/28/2018. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that $\beta = 0$ and $\beta = 1$. The last row reports the estimates for the fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates for the post-crisis period decreases and the estimates for REIBOR, STIBOR and the fixed effect panel becomes negative. The null hypothesis that β equals one can be rejected at the 1 percent significance level for all the IBOR rates and the fixed-effect panel except for NIBOR. Testing if β equals zero reveals that the β estimates for CIBOR, NIBOR and STIBOR are equal to zero, and rejected at the 1 percent significance level for REIBOR and the fixed-effect panel. The inflation after the crisis decrease and trended to its normal levels, making the overshooting problem to once again be a possible explanation for the deviation of UIP. The post-crisis period return estimates for the intercept, α, that are negative, but still close to the zero. The null hypothesis for the intercept, that α equals zero, can be rejected at the 1 percent significance level for all the IBOR rates and the fixed-effect panel. As for the pre-crisis period, the post-crisis period

gives negative β estimates, once again indicating an inverse relationship between the change in the spot exchange rate and the interest rate differential. If we compare the estimates between the pre- and post-crisis period, we can see that the estimates are more negative in the pre-crisis period and would therefore create a stronger inverse relationship. The estimates for the intercept turn negative, but as for the other two periods it remains close to zero.

As we can observe in appendix B, presenting the results for the rolling regression, the beta coefficient remains consistent through the first 12 sampling years. As our sampling period shrinks below 3 years the fluctuation increases, indicating a relationship between the stability of our beta coefficient ($\beta = 0$) and the size of our sampling period. In this case the crisis seemed to have no visible effect on the output, as the stability remained constant. These results resemble the ones obtained from Lothian and Wu (2011), where the coefficient remained stable over time. This shows us the effect of sample size on our different variables, as fluctuations was in fact very present as visible in figure B1 to B4, but not visible in the rolling regression during the years it took place (2007-2012).

Further, in appendix C we find the results for the extreme sampling. As we move from the 50 percentiles to the 90 percentiles, the estimates for the small absolute realization, β^S, converge to zero for CIBOR, NIBOR and STIBOR. However, the estimate for the small absolute realization for REIBOR increases and remains high as the percentile is increased. This violates the assumption of extreme sampling as the estimates for β^S should indicate a constant decrease towards zero. The estimates for the large absolute realization, β^L, increases and becomes more positive as higher percentiles are being used. This corresponds with the previously stated assumption and previous research for the estimate. For the STIBOR, it becomes negative as we increase the percentile from 50 to 90, resulting in a value that is slightly lower at the 90 percentiles than the initial value at the 50 percentiles. Deviation from the null hypothesis could be dependent on the economic fluctuations produced from the crisis included in the sampling period. As can be seen, the beta coefficient did not recover from the crisis in the case of Sweden. With this information, we can conclude that the larger interest rate differentials have a greater predictive power on the currency movements of the nation, this is once again supported by the results in appendix C and its representation of the volatility of the crisis period, with

the beta coefficient towards 1. We can also observe the non-linear relationship between the rate of exchange rate depreciation and the interest rate differential consistent with the results provided Lothian and Wu (2011).

5.2 Long-horizon

We now turn to the long-horizon test, using the yield to maturity for the government 10-year benchmark bonds. Testing UIP at a long-horizon has been made in several papers, where these papers have evaluated the theory using government bonds with equal maturities, also using a longer holding period, see Lothian and Wu (2011) and Meredith and Chinn (2004).

The robustness testing of the model is presented in appendix D. The first test preformed is to test the panel data, using the Hausman test and F-test. We cannot reject the null hypothesis for the Hausman test meaning that the model is in favor of the random-effect mode. As the subjects are fewer than the time in the panel regression, favoring the fixed-effect. We will therefore use the fixed-effect model. The null hypothesis for the F-test can be rejected at the 1 percent significance level, supporting our conclusion to use the fixed-effect model.

As for the short-horizon test, we start off with testing for a unit root to make sure the process is stationary. We performed the augmented Dickey-Fuller unit root test for the dependent and independent variables as well as the panel regression. Here we cannot reject the null hypothesis for the dependent variable, making it non-stationary. The same goes for the independent variable, where we cannot reject the null hypothesis. Meaning that as we have a unit root in both variables, we have a non-stationary process.

Furthermore, we once again utilize the individual-Fisher ADF test to strengthen the unit root testing. The panel unit root test reveals that the process is stationary, as we can reject the null hypothesis at the 1 percent significance level. By excluding the intercept, the combined p-values decline and supports the result that the process is stationary. We will once again rely on the unit root test for the panel regression as the results are more powerful and reliable (Levin, Lu & Chu, 2002). Hence, the process does not contain a common or individual unit root and therefore both the OLS regression and the panel regression process is stationary. As the process is stationary, we can utilize equation (7) and (8) to test the

uncovered interest parity at the long-horizon. In table 6, the results for the pre-crisis period is presented.

Table 6. Regression results for the pre-crisis period.

PRE-CRISIS 2000 - 2006	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\beta} = 1$	R^2	**N**
Denmark	0.038127* (0.021489)	-0.285181*** (0.082339)	***	0.191557	84
Iceland	0.002538 (0.023774)	-0.113217 (0.157085)	***	0.006501	16
Norway	0.011115 (0.018714)	-0.173006** (0.073381)	***	0.166669	84
Sweden	0.028249 (0.022527)	-0.291093*** (0.085240)	***	0.238630	84
Panel (FEM)	0.036636*** (0.009572)	-0.147004*** (0.048636)	***	0.056454	296

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 10-year government benchmark bond yields. The values in parentheses denotes the Newey and West standard errors. The sample period is 2000M01 to 2006M12. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that $\beta = 0$ and $\beta = 1$. The last row reports the estimates from a fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates for the pre-crisis period are all negative, with an average of roughly -0.20. We test if the β estimates are equal to one and conclude that we can reject the null hypothesis that β equals one for all the bond yields and the fixed-effect panel. As we did for the short-horizon test we also test if there is some influence of the β estimates with the hypothesis that β is equal to zero. We cannot reject that the β estimate for Iceland is equal to zero, whereas the others can be rejected at the 1 percent significance level. The negative β estimates tells that the change in the spot exchange rate and the differential of the yield to maturity exhibit the same inverse relationship as for the IBOR rates. The estimates for the intercepts, α, are close to zero, an indication that there is no constant risk-premium present. In order to confirm this, we also test the null hypothesis that α equals zero. This test reveals that we can reject the null hypothesis at the 1 percent significance level for CIBOR and the fixed-effect panel. The estimates for the pre-crisis period using the yield to maturity shows similarities to the estimates for the pre-crisis period using the IBOR

rates. Where, the β estimates are all negative and the majority of the estimates are significantly different from both zero and one.

Table 7. Regression results for the crisis period.

CRISIS 2007 - 2011	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\beta} = 1$	R^2	**N**
Denmark	0.022146 (0.022917)	0.055297 (0.160935)	***	0.005704	60
Iceland	0.001297 (0.015259)	-0.086545 (0.056437)	***	0.018540	60
Norway	0.112499*** (0.029280)	0.493007** (0.185685)	***	0.169138	60
Sweden	0.017024 (0.039529)	0.257518 (0.216301)	***	0.039057	60
Panel (FEM)	0.027899** (0.012389)	0.394976 (0.072251)	***	0.192847	240

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 10-year government benchmark bond yields. The values in parentheses denotes the Newey and West standard errors. The sample period is 2007M01 to 2011M12. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that $\beta = 0$ and $\beta = 1$. The last row reports the estimates from a fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates for the crisis period are positive for Denmark, Norway, Sweden and the fixed-effect panel, whereas it remains negative for Iceland. The null hypothesis that β equals one can be rejected for all the yield to maturities and the fixed-effect panel at the 1 percent significance level. However, we cannot reject that the estimate of β is equal to zero, except for Norway which can be rejected at the 5 percent significance level. The estimates for α are close to zero, and with the null hypothesis that it is equal to zero, it can only reject for Norway and the fixed-effect panel at the 1 percent significance level. As can be seen, the estimates obtained for the crisis period are positive, where only the estimate for Iceland is negative, and closer to one than the estimates for the pre-crisis period. This means that the crisis period produces estimates that are more in line with the theory of the uncovered interest parity. Comparing the results for the crisis period using the yield to maturity and the IBOR rates, the results for the IBOR rates are even closer to one, we even obtain β estimates that are equal to one.

Table 8. Regression results for the post-crisis period.

POST-CRISIS 2012 - 2018	$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\beta} = 1$	R^2	**N**
Denmark	-0.033455 (0.023171)	0.007326 (0.012177)	***	0.005666	84
Iceland	-0.001136 (0.003620)	-0.00047 (0.021782)	***	0.000020	84
Norway	-0.053127*** (0.016027)	-0.010679 (0.055715)	***	0.000835	84
Sweden	-0.020307 (-0.026179)	-0.026179 (0.018816)	***	0.037238	84
Panel (FEM)	-0.025909*** (0.006963)	-0.004294 (0.008524)	***	0.064166	336

*Note: the estimates above are obtained from the regression of regression equation (7) and (8), based on the 10-year government benchmark bond yields. The values in parentheses denotes the Newey and West standard errors. The sample period is 2012M01 to 2018M12. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively, for which we can reject the null hypothesis that* $\beta = 0$ *and* $\beta = 1$. *The last row reports the estimates from a fixed-effect panel regression. N reports the number of observations for each regression.*

The β estimates for the post-crisis period turns negative, except for Denmark that stays positive yet close to zero. We can reject the null hypothesis that β equals one at the 1 percent significance level for all the yield to maturities and the fixed-effect panel. Further, we cannot reject that β is equal to zero for any of the yield to maturities or the fixed-effect panel. As for the regression using the IBOR rates, the β estimates return to a negative value as we move from the crisis period to the post-crisis period. This implies that there is an inverse relationship between the change in the spot exchange rate and the yield to maturity, just as for the IBOR rates. The estimates for α also turns negative, where we can reject that α is equal to zero for Norway and the fixed-effect panel. As noted from the regressions using the yield to maturity for the benchmark bonds, the β estimates vary from negative to positive and none of the β's are in line with the theory of uncovered interest parity and is equal to one. One reason for the apparent failure using the yield to maturity is that when using long-term government bonds with coupon payments will create a measurement error in the regression, creating a bias of the independent variable towards zero. Alexius (1998) noted, that this limitation comes from that the yield to maturity will be different from the true return of the investment. One can disregard the coupon payments and use the yield to

maturity if the bond is traded at par and if the yield curve is flat (Alexius, 1998). We can observe this bias as we reject that the β estimates are equal to one for the three periods, generally accepting the null hypothesis that β equals zero.

As can be seen in appendix E, similarities of the rolling regression output between bonds and the IBOR's can be observed as the same trend of graphical consistency remains until the end-date. Yet the fluctuation for the bonds are greater than that of IBOR's, though it's important to note that this fluctuation is likely due to the difference in sample size rather than actual movements of the bonds return on investment. The only acceptance is that of Iceland, where the sample period decreases gradually. Here a downward trend of the beta coefficient can be observed, violating the provided hypothesis previously supported by all cases of rolling regression within this paper. Disregarding Iceland, one can observe the relationship between sample period and stability of the beta coefficient: As our sample period shrinks below 5 years, fluctuations of β increases.

Finally, in appendix F the results for the extreme sampling is presented. The estimates for the small absolute realizations, β^s, decreases and converges to zero as successively higher percentiles are being used for Denmark, Norway and Sweden. Whereas the estimates of β^s for Iceland increases as higher percentiles are used, a finding that moves in the wrong direction of our stated hypothesis for the small absolute realizations. The estimates for the large absolute realizations, β^L, increases and becomes more positive for Denmark, Norway and Sweden as a higher percentile is being used, which is in line with the hypothesis for the extreme sampling. The estimates for the large absolute realizations for Iceland become successively lower as the percentile is being increased, a result that moves against the theory of the extreme sampling. The relatively large effect of the financial crisis on Iceland could be a deterministic factor for the values produced. Table 6 to 8 reflects this as Iceland consistently throughout the 3 periods produce a negative beta coefficient. It is also the only country with a negative beta coefficient during the economic crisis of 2007 and is thus the furthest away from the null hypothesis of an β equal to one.

5.3 Discussion

The results of our regression are something that should be further analyzed, as they strongly oppose previous research in this field. Further, as we found support for the UIP

theory holding superior for the crisis period, the scarcity of previous research with similar results gives rise to further discussions. If we look at the U.S., denoted as the domestic country in our paper, one reasoning behind these results could be due to the overshooting of inflation expectations. As examined by Belongia and Ireland (2016), the years of 2001 and 2007 signaled a decreased weight in the stability of inflation, a deviation from the established policy rules of 2001 of a two percent target inflation. This resulted in an initial relatively low inflation influencing the choices of the policy makers. The inflation rose as the crisis of 2007 approached, resulting in a situation of overshooting of the inflation expectations. (Belongia & Ireland 2016). We hypothesize that the estimates produced in the short-horizon crisis period is the result of the overshooting, as a larger inflation is produced during the crisis equaling the larger expected inflation, thus producing β coefficients in line with the theory of UIP. Another possible explanation for the results is the manipulation of short run interest rates, conducted by the central banks. This will affect both assets and liabilities within the system, altering the funds related to these assets, resulting in a change of the interest rates. This was further examined and proven by Cecchetti (2008) by observing the balance sheets of the central banks between 2007-2008. He concluded that by lending both cash and security based on collateral values, the central bank attempted to stabilize the economy and its interest rates, of which nearly 600 million dollars were invested (Cecchetti. 2008). This could explain why the coefficients produced during the crisis period were in line with the UIP theory, as the central bank manipulated the short-term interest rates to stabilize the economy. Additionally, an algebraic explanation could be that the risk premium is not equal to zero, nor is constant. If the risk premium varies over time, this could result in the α estimate to be larger in magnitude than both the interest rate differential and the spot exchange rate, compensating for a lack of predictor power produced by the model.

5.3.1 Limitations

This thesis comes with some limitations. First, the use of the coupon paying government benchmark bonds made the slope parameter biased towards zero, which lead us to reject the null hypothesis that β is equal to one for all the periods. Second, our aim was to test the UIP between smaller economies. As we included the United States to fully see the effects of the financial crisis, we are not fully able to see the effect of UIP between smaller economies.

6. Conclusion

The primary results to be observed in this paper is that the uncovered interest parity performed better during the crisis period. As supported by Chaboud and Wright (2005), as well as Lothian and Wu (2011), greater economic fluctuation and volatility within a country strengthens the predictive power of uncovered interest parity due to an increase of the interest-rate differential. This as, the rational expectations of the future spot exchange rate can more easily be determined and interpreted by larger interest-rate differentials. This is strengthened by the extreme sampling regression output for both the short- and long-horizon. As successively larger interest rate differentials were used, we obtained results that converged towards the UIP theory, with β estimates equal to 1. These results are especially true for the short-horizon test, where we obtained beta estimates with an average of 1.20. Compared to the beta estimates of the long-horizon with an average of 0.228 where we could reject the null hypothesis of equaling 1 for all the bonds. The pre-crisis period and the post-crisis period produced estimates that was negative. These results are more in line with previous research and shows the inverse relationship, where we observe and appreciation rather than a depreciation of the currency, which is an inverse relationship of the UIP theory. For these two periods we could reject the null hypothesis that is equal to one, providing less support for UIP. As evident by the smaller interest rate differentials for these periods. The long-horizon test had one limitation, in that the yield to maturity biased the independent variable towards zero and therefore we could reject the null hypothesis that equals one for all the sample periods. Overall, we can say that the results from our regressions do not support our assumptions underlying the tests. We expected the long-horizon test to produce reliable results, better than the ones obtained from the short-horizon. What we found was that the crisis period was able to improve our results, especially for the short-horizon.

For future research we would suggest evaluating the UIP using zero-coupon bonds or the duration of the bonds, as this will produce unbiased estimates of the independent variable, hence they will no longer be biased towards zero. Further, it would be interesting to test UIP using one of the Scandinavian countries as the domestic country, thereby excluding the U.S. from the regression.

7. List of references

Alexius, A. (1998). *Uncovered interest parity revisited.* Economics Department, Stockholm*:* Sveriges Riksbank. Retrieved from: http://archive.riksbank.se/Documents/Rapporter/Working_papers/1990_1998/WP%2053.pdf

Arellano, M. (1993). *On the testing of correlated effects*. Journal of Econometrics, pp. 87-97. North – Holland. Retrieved from: https://www.cemfi.es/~arellano/Arellano_1993_JEtrics.pdf

Barbieri, L. (2006). *Panel Unit Root Tests: A review*. Economia – Quaderno No. 44. Milano. Retrieved from: https://dipartimenti.unicatt.it/dises-wp_rossa_06_44.pdf

Belongia, M.T. & Ireland, P.N. (2016). *The evolution of U.S. monetary policy: 2000 – 2007.* NBER Working Paper, No. 22693. Cambridge, Massechusetts. Retrieved from: https://www.nber.org/papers/w22693.pdf

Bodie, Z., Kane, A. & Marcus, A.J. (2014). *Investments. 10th Global Edition.* Maidenhead*:* McGraw-Hill Inc*.* ISBN-13: 9780077161149

Cecchetti, S.G. (2008). *Crisis and responses: The federal reserve and the financial crisis of 2007 – 2008.* NBER Working Paper, No. 14134. Cambridge, Massachusetts. Retrieved from: https://www.nber.org/papers/w14134.pdf

Chaboud, A. P., & Wright, J.H. (2004). *Uncovered interest parity: it works, but not for long*. Journal of International Economics*,* pp. 349 – 362. Washington, DC: International Finance Division. //doi.org/10.1016/j.jinteco.2004.07.004

Cheng, J., Taylor. L, W., & Weng. W. (1999). *Beyond the purchasing power parity: testing for cointegration and causality between exchange rates, prices, and interest rates.* Journal of Post Keynesian Economics*,* Vol. 29. No. 2 259. Taylor & Francis, Ltd. Retrieved from: https://www.jstor.org/stable/4539015?seq=1#metadata_info_tab_contents

Cieplinski, A. & Summa, R. (2015). *Keynesian roots of interest parity theorems.* University of Siena & University of Rio de Janeiro. Retrieved from: https://www.academia.edu/12165747/Keynesian_Roots_of_Interest_Parity_Theorems

Cournot, A. (1838). *Researchers into the mathematical principles of the theory of wealth.* The MacMillan Company, London, England.

Crotty, J. (2009). *Structural causes of the global financial crisis: A critical assessment of the "new financial architecture".* Cambridge Journal of Economics, Vol. 33, pp. 563-580. //doi.org/10.1093/cje/bep023

Dandan, L., Goshray, A. & Morley, B. (2011). *Uncovered interest parity and the risk premium*. University of Bath Department of Economics. Retrieved from: http://www.bath.ac.uk/economics/research/working-papers/2011-papers/02-11.pdf

Flood, R.P., & Rose, A.K. (2002). *Uncovered interest parity in crisis.* IMF staff papers, Vol. 49, No. 2. International Monetary Fund. Retrieved from: https://www.imf.org/External/Pubs/FT/staffp/2002/02/flood.htm

Frankel, J.A. (1979). *On the mark*: *A theory of floating exchange rates based on real interest differentials.* The American Economic Review, Vol. 69, No. 4, pp. 610 – 622. Retrieved from: https://www.jstor.org/stable/1808707?seq=1#metadata_info_tab_contents

Gärtner, M. (2016). *Macroeconomics 5th edition.* Harlow, United Kingdom: Pearson Education Limited. ISBN-13: 9781292115207.

Froot, K. A. & Thaler, R. H. (1990). *Anomalies: foreign exchange.* Journal of economic perspectives Vol. 4, number 3, pp. 179 – 192. Retrieved from: https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.4.3.179

Granlund, K. & Rehnby, N. (2018). *Reference rates are changing*. Finansinspektionens författningssamling. Finansinspektionen. Retrieved from:

https://www.fi.se/contentassets/0f2f5ae87e6e4f0b8c2af671b3d84420/fi-analys-14-referensrantor-2018-11-28_eng.pdf

Gujarati, D. & Porter, D.C. (2009). *Basic Econometrics. 5th edition.* New York, U.S: McGraw-Hill Inc. ISBN-13: 9780073375779

Hodrick, R. J. & Bekaert, G. (1993). *On biases in the measurement of foreign exchange risk premiums.* Journal of International Money and Finance, Vol. 12, pp. 115 – 138. Retrieved from: https://www0.gsb.columbia.edu/faculty/rhodrick/biasesinmeasurement.pdf

Hull, J. & White, A. (2013). *LIBOR vs. OIS: The derivatives discounting dilemma*. Journal of Investment Management, Vol. 11, No.3, pp. 14-27. Retrieved from: https://www-2.rotman.utoronto.ca/~hull/DownloadablePublications/LIBORvsOIS.pdf

Isard, P. (1991). *Uncovered interest parity*. International Monetary Fund Research Department. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=884827##

Keynes, J.M. (1923). *The collected writings of Johan Maynard Keynes: A tract on monetary reform, Vol. 4.* Cambridge University Press for the Royal Economic Society, Cambridge, England. ISBN-13: 9781107677722

Krugman, P.R., Obstfeld, M. & Melitz, M. (2015). *International Economics: Theory and policy (Global Edition), 10th edition.* Boston: Pearson Education Limited. ISBN-13: 9781292019550

Levin, A., Lin, F-L., & Chu, C-S, J. (2002) *Unit root tests in panel data: Asymptotic and finite-sample properties.* Journal of Econometrics, Vol. 108, issue 1, pp. 1 – 24. https://doi.org/10.1016/S0304-4076(01)00098-7

Lothian, J.R. & Wu, L. (2011). *Uncovered interest rate parity over the past two centuries.* Journal of International Money, Vol. 30, issue 3, pp. 448 – 473. https://doi.org/10.1016/j.jimonfin.2011.01.005

McCallum, B.T. (1994). *A reconsideration of the uncovered interest parity relationship*. Journal of International Economics, pp. 105 – 132. NBER Working Paper, No. 4113. Cambridge, Massachusetts. Retrieved from: https://www.nber.org/papers/w4113.pdf

Meredith, G. & Chinn, M.D. (2004). *Monetary policy and long-horizon uncovered.* International Monetary Fund. IMF Staff Papers, Vol. 51, No. 3. Retrieved from: https://www.imf.org/External/Pubs/FT/staffp/2004/03/pdf/chinn.pdf

Mussa, M. (1979). *Empirical Regularities in the behaviour of exchange rates and theories of the foreign exchange market.* Carnegie-Rochester conference series on public policy, Vol. 11, pp. 9 – 57. https://doi.org/10.1016/0167-2231(79)90034-4

Persson, M. (2012). *The Riksbank's review of STIBOR.* Sveriges Riksbank. Stockholm, Sweden. Retrieved from: http://archive.riksbank.se/Documents/Rapporter/Riksbanksstudie/2012/rap_riksbanksstudie_stibor_121128_eng.pdf

Ricardo, D. (1811). *The high price of bullion, a proof of the depreciation of bank notes.* London, England. Retrieved from: http://repository.tku.ac.jp/dspace/bitstream/11150/5550/1/LAUD_059-18.pdf

Tang, K.B. (2010). *The precise form of uncovered interest parity: A heterogenous panel application in economic modelling.* Journal in Economic Modelling. Vol. 28, issues 1-2. University of Nottingham. Selangor, Malaysia. https://doi.org/10.1016/j.econmod.2010.06.015

Taylor, M.P. (1995). *The Economics of exchange rates*. Journal of Economic Literature, Volume 14. Cambridge university press. US. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.587.5069&rep=rep1&type=pdf

Tsiang, S.C. (1958). *A theory of foreign-exchange speculation under a floating exchange system.* The Journal of political economy. Vol. 66, No. 5, pp. 399 – 418. Retrieved from: https://www.jstor.org/stable/1826668?seq=1#metadata_info_tab_contents

8. Appendices

Appendix A. Robustness test for short-horizon

Table A1. Hausman test and F-test for panel regression.

Hausman test	Statistic
Cross-section random	52.778152***
F-test	**Statistic**
Cross-section F	23.926463***

*Note: the table presents the results for the Hausman and F-test for the panel regression. The Hausman is based on the Chi-square statistic. The F-test uses the F-statistic in the testing. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table A2. ADF unit root test for dependent variables.

ADF test for, $\Delta s_{t,t+k}$	**With intercept**			
	Denmark	**Iceland**	**Norway**	**Sweden**
ADF test statistic	-5.840373***	-5.320967***	-6.267978***	-6.162325***
	Without intercept			
ADF test statistic	-5.842601***	-5.319126***	-6-261029***	-6.16142***

*Note: the table reports the augmented Dickey-Fuller unit root test for the dependent variable. The ADF test statistic reports the t-statistic for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table A3. ADF unit root test for independent variables.

ADF test for, $\beta(i_{t,k} - i^*_{t,k})$	**With intercept**			
	Denmark	**Iceland**	**Norway**	**Sweden**
ADF test statistic	-0.847347	-1.465628	-1.767283	-1.151866
	Without intercept			
ADF test statistic	-0.787903	-1.071003	-2.438148**	-1.099065

*Note: the table reports the augmented Dickey-Fuller unit root test for the independent variable. The ADF test statistic reports the t-statistic for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table A4. Individual-Fisher ADF panel unit root test, including the intercept.

Panel unit root test	**Statistic**	**Cross-section**
Common unit root (Levin, Lin & Chu)	-0.09850	4
Individual unit root (Fisher ADF)	4.19369	4
Individual unit root process, cross section	**Prob.**	**Lag**
CIBOR	0.6971	9
REIBOR	0.8049	29
NIBOR	0.3972	5
STIBOR	0.5512	9

*Note: the table reports the panel unit root test including the intercept. The common unit root test is preformed using the Levin, Lin and Chu t-statistic. The individual unit root is tested using the individual-Fisher ADF test. The tests uses the combined p-values. The bottom part of the table reports the individual unit root process for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

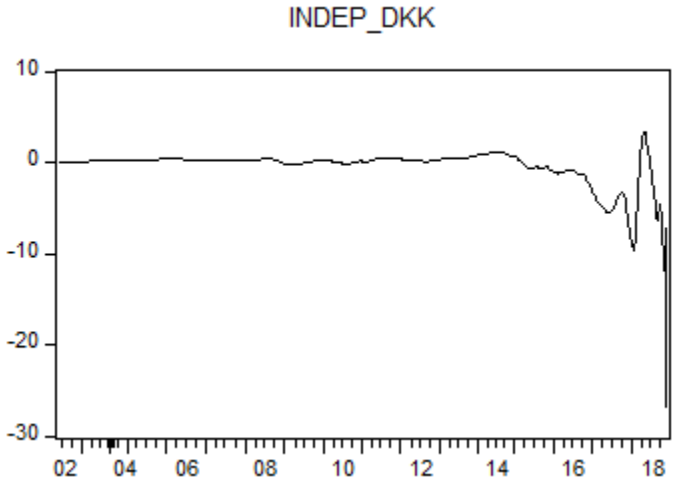
Table A5. Individual-Fisher ADF panel unit root test, excluding the intercept.

Panel unit root test	**Statistic**	**Cross-section**
Common unit root (Levin, Lin & Chu)	-2.59899***	4
Individual unit root (Fisher ADF)	15.9655**	4
Individual unit root process, cross section	**Prob.**	**Lag**
CIBOR	0.3750	9
REIBOR	0.2575	29
NIBOR	0.0143**	5
STIBOR	0.2470	9

*Note: the table reports the panel unit root test excluding the intercept. The common unit root test is preformed using the Levin, Lin and Chu t-statistic. The individual unit root is tested using the individual-Fisher ADF test. The tests uses the combined p-values. The bottom part of the table reports the individual unit root process for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

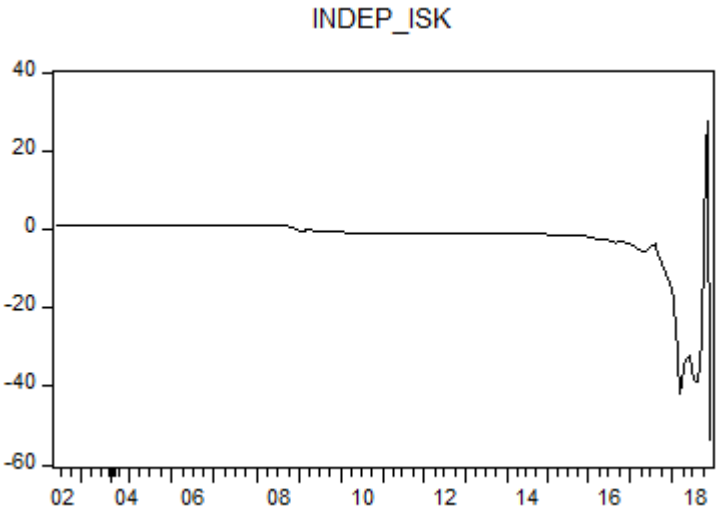
Appendix B. Rolling regression short-horizon

Figure B1. Rolling regression for Denmark.



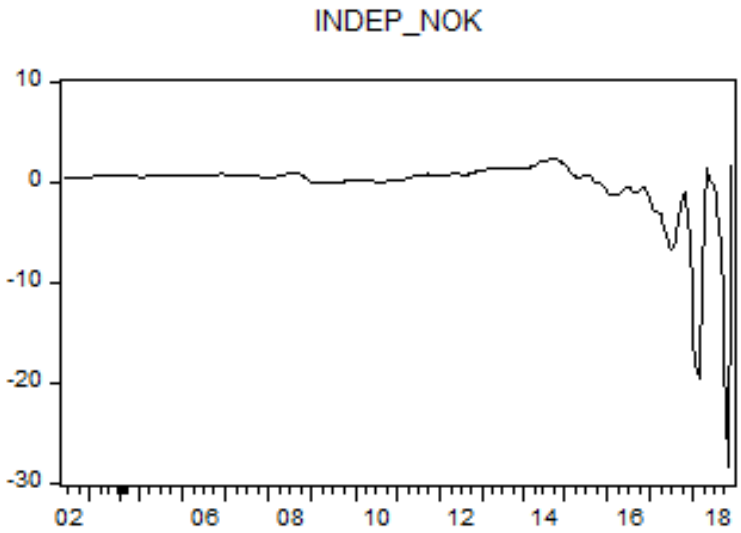
Note: rolling regression for Iceland. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period

Figure B2. Rolling regression for Iceland.



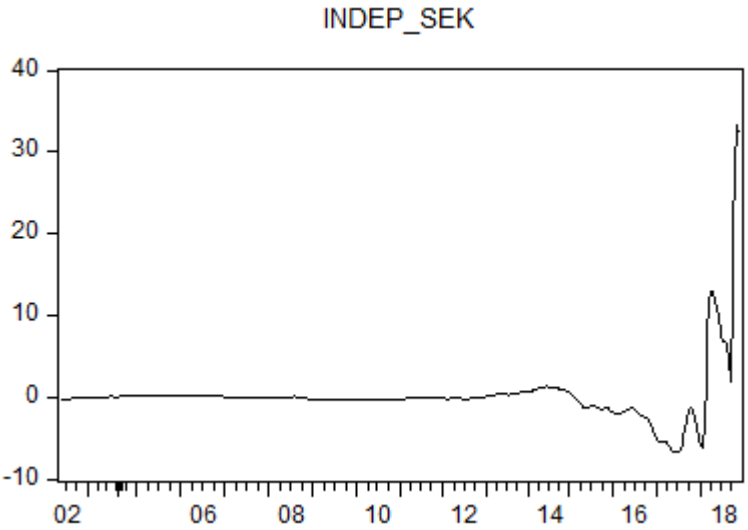
Note: rolling regression for Iceland. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period.

Figure B3. Rolling regression for Norway.



Note: rolling regression for Norway. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period.

Figure B4. Rolling regression for Sweden.



Note: rolling regression for Sweden. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period.

Appendix C. Extreme sampling short-horizon

Table C1. Extreme sampling.

Extreme Sampling	Percentile	α	β^S	β^L	$\|dr\|$	R^2
CIBOR (Denmark)	50	0.003488 (0.002852)	0.211044 (0.441451)	-0.131238 (0.207977)	-0.013880	0.001662
	70	0.004021 (0.001309)	-0.498850 (0.113015)	-0.119094 (0.106262)	0.000937	0.006158
	90	0,001162 (0,002605)	-0,148714 (0,306907)	0,167709 (0,219674)	0.013954	0.001486
REIBOR (Iceland)	50	0.034097 (0.022284)	0.699278 (0.350531)	0.504566 (0.542028)	-0.056090	0.043214
	70	0.067943 (0.024332)	1.056645 (0.374831)	1.811941 (0.687425)	-0.047620	0.054224
	90	0.060964 (0.020460)	1.003440 (0.338514)	2.665071 (0.785281)	-0.036110	0.058127
NIBOR (Norway)	50	0.004208 (0.005180)	0.403118 (0,298604)	-0.130614 (0.454731)	0.000003	0.006759
	70	0.000491 (0.001320)	-0.674661 (0,100021)	-0.065785 (0.095921)	0.009138	0.013530
	90	0.000255 (0.001077)	-0.135253 (0.055558)	0.812113 (0.200788)	0.019711	0.004983
STIBOR (Sweden)	50	-0.003316 (0.006114)	-0.533785 (0.432074)	0.078716 (0.345999)	-0.001430	0.005091
	70	-0.01339 (0.001392)	-0.398676 (0.105452)	-0.010966 (0.101128)	0.013337	0.004590
	90	0.000600 (0.002876)	-0.239390 (0.167761)	0.039634 (0.378036)	0.024877	0.003919

Note: The regressions performed are based on the 3-month interbank offering rates (IBOR), the estimates reported are generated using the extreme sampling regression: where S and L denotes small and large realizations of the absolute value of the interest rate differentials. The entries reported under $\|dr\|$ reports the threshold value of the interest rate differentials. Estimates for α, β^S, and β^L are reported for each country and percentile, where the value in parentheses reports the standard errors, the standard errors are constructed based on HAC Newey and West.

Appendix D. Robustness test for long-horizon

Table D1. Hausman test and F-test for panel regression.

Hausman test	Statistic
Cross-section random	0.351460
F-test	**Statistic**
Cross-section F	2.800029**

*Note: the table presents the results for the Hausman and F-test for the panel regression. The Hausman is based on the Chi-square statistic. The F-test uses the F-statistic in the testing. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table D2. ADF unit root test for dependent variables.

ADF test for, $\Delta s_{t,t+k}$	**With intercept**			
	Denmark	**Iceland**	**Norway**	**Sweden**
ADF test statistic	-5.708585***	-2.342269	-5.471310	-5.547326
	Without intercept			
ADF test statistic	-5.788513***	-2.349469**	-5.553373***	-5.613771***

*Note: the table reports the augmented Dickey-Fuller unit root test for the dependent variable. The ADF test statistic reports the t-statistic for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table D3. ADF unit root test for independent variables.

ADF test for, $\beta(i_{t,k} - i^*_{t,k})$	**With intercept**			
	Denmark	**Iceland**	**Norway**	**Sweden**
ADF test statistic	-1.184922	-2.606397	-2.308577	-1.184922
	Without intercept			
ADF test statistic	-2.005204**	-3.489533***	-3.092122***	-3.092122***

*Note: the table reports the augmented Dickey-Fuller unit root test for the independent variable. The ADF test statistic reports the t-statistic for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

Table D4. Individual-Fisher panel unit root test, including intercept.

Panel unit root test	**Statistic**	**Cross-section**
Common unit root (Levin, Lin & Chu)	-2.42035***	4
Individual unit root (Fisher ADF)	29.0485***	4
Individual unit root process, cross section	**Prob.**	**Lag**
Denmark	0.3115	16
Iceland	0.0777*	16
Norway	0.0024***	16
Sweden	0.0084***	16

*Note: the table reports the panel unit root test including the intercept. The common unit root test is preformed using the Levin, Lin and Chu t-statistic. The individual unit root is tested using the individual-Fisher ADF test. The tests uses the combined p-values. The bottom part of the table reports the individual unit root process for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

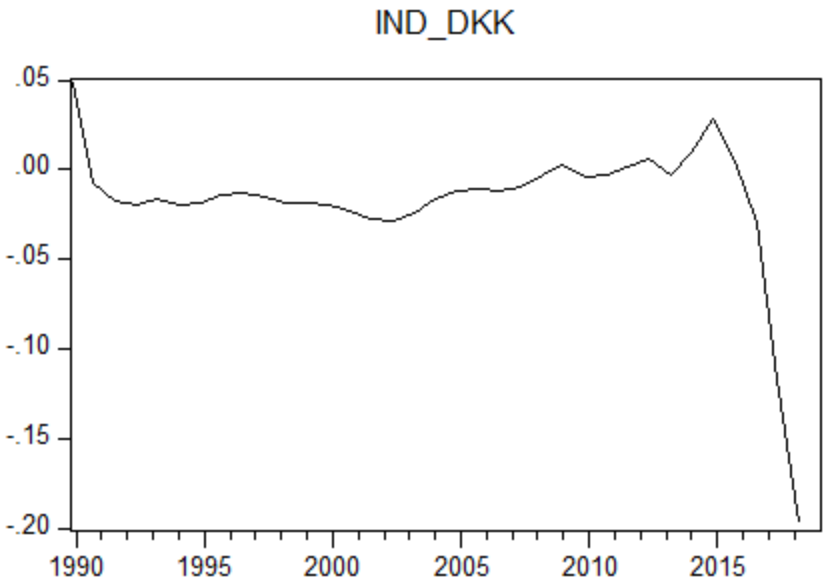
Table D5. Individual-Fisher panel unit root test, excluding the intercept.

Panel unit root test	**Statistic**	**Cross-section**
Common unit root (Levin, Lin & Chu)	-5.80974***	4
Individual unit root (Fisher ADF)	52.0671***	4
Individual unit root process, cross section	**Prob.**	**Lag**
Denmark	0.0262***	0
Iceland	0.0053***	0
Norway	0.0001***	0
Sweden	0.0005***	0

*Note: the table reports the panel unit root test excluding the intercept. The common unit root test is preformed using the Levin, Lin and Chu t-statistic. The individual unit root is tested using the individual-Fisher ADF test. The tests uses the combined p-values. The bottom part of the table reports the individual unit root process for each country. *, **, *** indicates the 10 percent, 5 percent, and 1 percent significance level, respectively.*

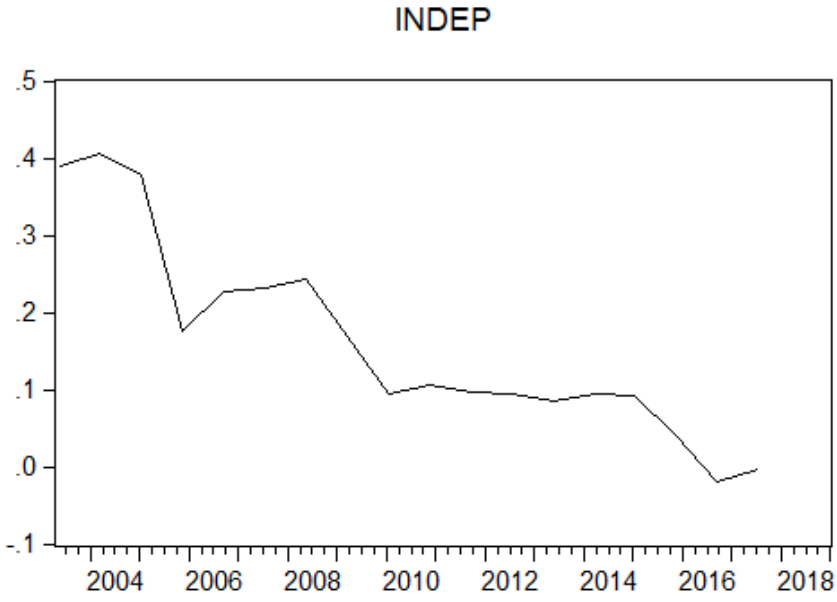
Appendix E. Rolling regression long-horizon

Figure E1. Rolling regression for Denmark.



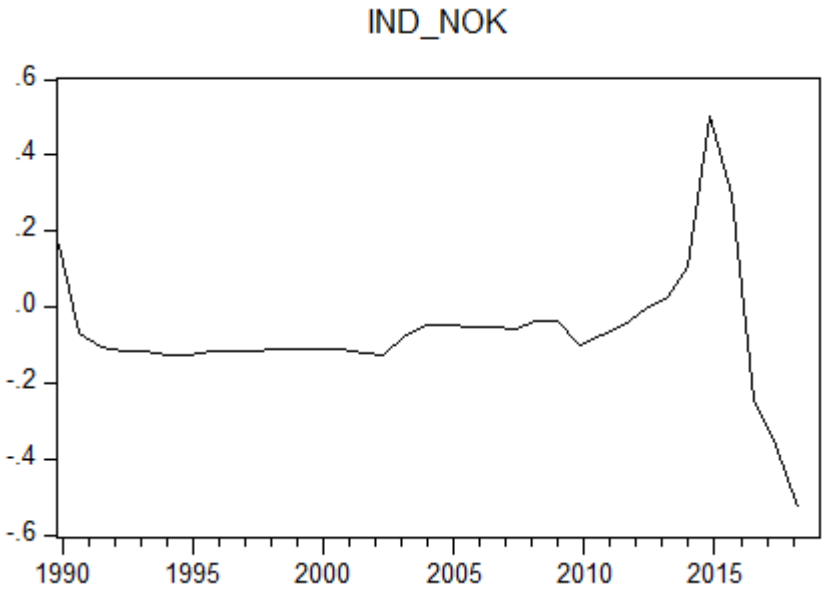
Note: rolling regression for Denmark. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period

Figure E2. Rolling regression for Iceland.



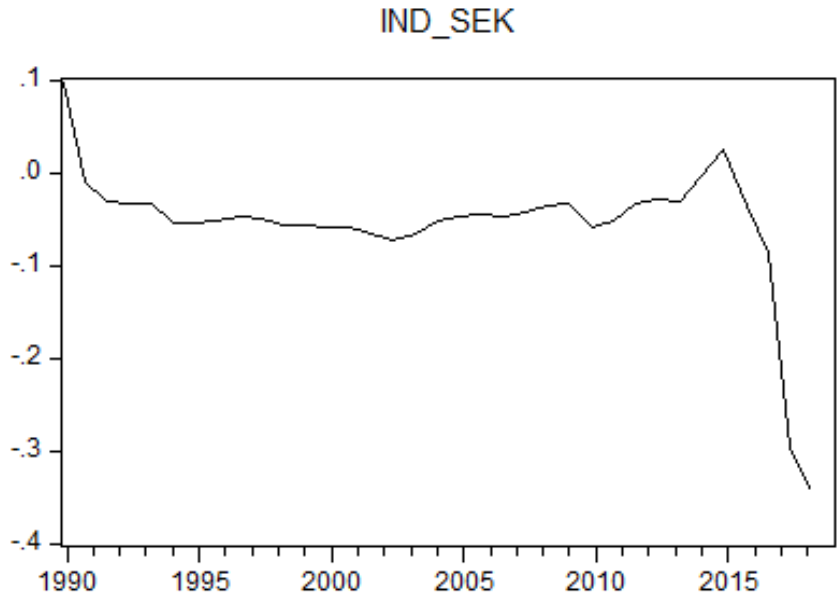
Note: rolling regression for Iceland. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period

Figure E3. Rolling regression for Norway.



Note: rolling regression for Norway. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period

Figure E4. Rolling regression for Sweden.



Note: rolling regression for Sweden. The end date of December 2018 is anchored on the horizontal axis. The vertical axis measures the beta coefficient, and shows its sensitivity to the sampling period

Appendix F. Extreme sampling long-horizon

Table F1. Extreme sampling.

Extreme Sampling	Percentile	α	β^s	β^L	$\|dr\|$	R^2
Denmark	50	0.000782 (0.023498)	0.676388 (0.018021)	-0.010941 (0.018021)	0.021214	0.059193
	70	-0.027347 (0.019745)	0.533248 (0.442512)	0.004956 (0.015840)	0.191632	0.051086
	90	-0.073852 (0.049956)	0.138577 (0.148947)	0.029268 (0.023936)	1.305995	0.018032
Iceland	50	0.035125 (0.046744)	0.332440 (0.197227)	0.187516 (0.241382)	-0.083344	0.086852
	70	0.032694 (0.049632)	0.321806 (0.202804)	0.204773 (0.257737)	0.045327	0.085880
	90	0.045751 (0.049652)	0.385896 (0.190084)	0.016239 (0.155291)	0.219970	0.105080
Norway	50	-0.015286 (0.024481)	0.373506 (0.346220)	-0.086740 (0.097803)	-0.10486	0.025552
	70	-0.012566 (0.031099)	0.371777 (0.365996)	-0.086388 (0.119526)	0.037403	0.023137
	90	-0.048766 (0.022981)	0.222805 (0.246400)	0.040454 (0.070696)	0.311365	0.016313
Sweden	50	0.038177 (0.031985)	0.642046 (0.367240)	-0.072147 (0.033586)	0.019401	0.151227
	70	0.008411 (0.022135)	0.558235 (0.326686)	-0.046224 (0.025967)	0.176035	0.137289
	90	-0.063979 (0.036377)	0.260907 (0.185574)	0.007510 (0.025964)	1.104039	0.069699

Note: The regressions performed are based on the 10-year government benchmark bond yields, the estimates reported are generated using the extreme sampling regression: where S and L denotes small and large realizations of the absolute value of the interest rate differentials. The entries reported under $\|dr\|$ reports the threshold value of the interest rate differentials. Estimates for α, $\beta^S, and\ \beta^L$ are reported for each country and percentile, where the value in parentheses reports the standard errors, the standard errors are constructed based on Newey and West.