Purchasing Power Parity in the Nordic Countries

Master Thesis: Master of Business Administration

by

Artur Tambiev*

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Abstract

This paper tests for purchasing power parity (PPP) between four Nordic countries and the Eurozone using monthly observations from 2000 to 2014. The study employes the Johansen test for cointegration. Johansen method indicates the absence of cointegration for all countries except Sweden and further shows the existence of one cointegration vector. Thus, this study confirms the validity of PPP in the long-run for Sweden only.

Oslo and Akershus University College of Applied Sciences

School of Business

Pilestredet 46 | 0130 Oslo

*student number: s190125

1 Introduction

The theory of purchasing power parity (PPP) states that the nominal exchange rate between two currencies should be equal to the ratio of aggregate price levels between two countries. Hence, a unit of currency of one country will have the same purchasing power in a foreign country (Taylor and Taylor, 2004).

The PPP concept is an important element of international macroeconomics. Studies within this field are critical not only for empirical researchers but also for policy-makers. Testing the validity of PPP theory is very important because first, it forms the foundation of exchange rate economics, and second, as a measure of long-run equilibrium exchange rate, its validity has important policy implications.

The validity of PPP has been extensively tested, especially for developed countries, as illustrated by studies done by Froot and Rogoff (1995), Frankel and Rose (1996), Lothian and Taylor (1997, 2000). In general, these studies concluded that the PPP holds in the long-run.

The objective of this paper is to investigate PPP theory for the four Nordic countries Denmark, Iceland, Norway and Sweden by using the Johansen (1988, 1991) maximum eigenvalue and trace cointegration tests. The variables involved in the PPP relationship must have certain order of integration in order to cointegrate. I therefore test for the order of integration first applying the ADF unit root test before I run the Johansen cointegration test.

The results from Johansen cointegration test illustrates that there is a long-run equilibrium relationship among the nominal exchange rate, the domestic prices and the foreign prices, for all countries involved in the analysis. These results support the PPP hypothesis as a long-run equilibrium condition.

The rest of the paper is organized as follows: Section 2 presents the literature review. Section 3 gives an overview of the PPP concept. Section 4 explores the data to be used. Section 5 outlines the methodology. Section 6 presents the empirical results. Finally, section 7 consists of concluding remarks.

2 Literature Review

Many researchers have conducted empirical tests to study the validity of PPP. The unit root and cointegration based studies (performed from the late 1980s and on) have provided mixed results for the validity of PPP (Froot and Rogoff (1995)).

[0]**Acknowledgments;** a special thanks go to associate prof. Fredrik Wulfsberg who provided encouraging and constructive feedback that considerably improved the contents and quality of this paper.

Single-equation method of cointegration, as originally developed by Engle and Granger (1987), almost always fail to find cointegration between the nominal exchange rate and the prices (Taylor, 1988; Ardeni and Lubian, 1991). The system methods, mainly the Johansen method, provide evidence of cointegration (Edison et al., 1997; Juselius, 1995; Cheung and Lai, 1993).

The validity of the PPP has been extensively tested, both for developed and developing countries. Rashid and Amit (2008), using Johansen method and monthly data to test long-run relationship among nominal exchange rates and prices between Sweden and USA, finds evidence in favour of PPP in the long-run.

Serletis (1994) tests the PPP relationship using quarterly data over the recent fluctuating exchange rate period for seventeen OECD countries in a trivariate framework, with both the United States and Germany as base countries. The paper provides evidence of long-run PPP for Greece, Norway, Spain, and the United Kingdom in the case of dollar-based exchange rates and for Austria, Finland, and Spain in the case of Deutsche-mark-based exchange rates.

Choudry (1999) tests for cointegration between relative prices and nominal exchange rates of the currencies of Poland, Romania, Russia and Slovenia vis-a-vis the US dollar. The study finds evidence of cointegration, which he interprets as positive evidence for the validity of PPP for the economies of Russia and Slovenia.

Christev and Noorbakhsh (2000) tests for the PPP for six Central and East European countries, applying the Stock and Watson and the Johansen cointegration methodologies. The study finds evidence for long-run equilibrium, however, the cointegration vectors reject the symmetry and proportionality restrictions implied by the PPP.

Weliwita (1998), applying Granger two-step cointegration procedure and Johansen multivariate cointegration technique for six developing countries in Asia, reject the existence of long-run PPP for all six countries (India, Indonesia, Malasia, Pakistan Sri Lanka and Thailand). The study employed monthly data on prices and exchange rates for the period 1981-1994.

Sulku (2010) investigates the PPP hypothesis for 16 Less Developed Countries (LDCs), from all over the world, during their fixed and flexible exchange rate regimes over the period from 1957-1999. The study finds only a few and a nearly equal evidence in favour of PPP under the alternative regimes in LDCs.

Kargbo (2003) tests whether there is empirical support for PPP in Africa using Johansen cointegration technique on annual data for black market exchange rates and consumer price indices in 30 countries from 1960-1997. The author found strong support for the PPP doctrine as a useful guide for exchange rate policy reform in Africa.

Overall, the conclusion of empirical research studies of PPP using the cointegration method so far are mixed. The main highlights from these studies are the importance of the data. The null hypothesis of no-cointegration is more easily rejected when, in the sample period considered, the exchange rates are fixed rather than floating. Also, the support and use of different price indices (WPI, CPI and GDP) is mixed.

3 Purchasing Power Parity

Taylor (2003) defines PPP as: "The purchasing power parity exchange rate is the level of the nominal exchange rate such that the purchasing power of a unit of currency is exactly the same in the foreign economy as in the domestic economy, once it is converted into foreign currency at that rate."

PPP can also be viewed as the international version of the law of one price (LOP). The LOP states that in the absence of trade barriers, such as transportation costs and tariffs, competition will equalize the price of identical and traded goods across countries when the prices are expressed in the same currency. However, PPP is rather tested as a long-run parity condition because of the different adjustment time between assets and goods prices in case of deviation from the equlibrium level (i.e. "sticky prices"). Therefore, economists generally believe that PPP should hold in the long-run (Sarno and Taylor, 2002).

Thus, the PPP theory is motivated by an arbitrage argument. It claims that the purchasing power of for example 1 EUR should be the same whether it is spent at home or abroad.[1] The argument for why the PPP theory should hold is that if it did not, each consumer would presumably spend 1 EUR where it can buy more units of the consumption bundle. Thus, people would spend money abroad instead of at home if they could buy more goods abroad than at home for 1 EUR.[2] In turn, this would depreciate the domestic currency and people will acquire the foreign currency to buy the foreign goods.

The relative attractiveness of domestic goods compared to foreign goods depends primarily on their relative price. The relative prices can be seen as the number of domestic goods that must be given up to acquire one foreign good. This relative price is called the real exchange rate. Thus, the theory of PPP can be seen as a theory about the determination of the real exchange rate, which is defined by:

$$R_t = \frac{E_t P_t^*}{P_t} \tag{1}$$

[1]Since $1/P_t$ is the purchasing power of 1 EUR over the price of the domestic consumption bundle, and since 1 EUR is worth $1/E_t$ units of the foreign currency, each of which can buy $1/P_t^*$ consumption bundles abroad, if the purchasing power of 1 EUR is equalized at home and abroad, this means: $1/P_t = (1/E_t)(1/P_t^*)$, which implies $E_t P_t^*/P_t = R_t = 1$.

[2]Assuming no transportation and transaction costs.

where E_t is the spot exchange rate measured in units of foreign currency per unit of domestic currency, P_t is the price level of domestic goods (i.e. a representative basket of goods produced in the home country), and P_t^* is the price level of foreign goods (again, a representative basket of goods). The P_t and P_t^* can be corresponded to aggregate price indices, such as the whole sale price index (WPI) or consumer price index (CPI), that measures the domestic currency price of basket of goods and services purchased by consumer.[3]

From equation (1) we can see that an increase in R_t (depreciation) can be brought about either by an increase in E_t (a nominal depreciation), by an increase in P_t^*/P_t (a reduction in country's price level relative to that of its trading partner), or both of them. But it is also possible for R_t to fall (to appreciate) while E_t is rising (depreciating) if $P_t * /P_t$ falls by more than enough to offset the increase in E_t.

3.1 Absolute and relative PPP

There are two versions of PPP: the "absolute" and the "relative" PPP. Absolute PPP is the strongest version and states that the domestic and foreign bundles of goods should sell for the same price when expressed in a common currency. Absolute PPP requires that the real exchange rate is on average equal to one:

$$R_t = \frac{E_t P_t^*}{P_t} = 1 \tag{2}$$

In an ideal world with no transaction costs, transportation and shipping costs, and all goods are traded internationally, the absolute PPP should hold for each good individually. However, due to barriers like transaction costs, non-tradability etc., absolute PPP may not hold perfectly in practice. (Taylor, 2003).

The "weak" or "relative" version of PPP acknowledges that because the bundles of goods tested in the practice are different and the absolute prices of these consumption baskets may not be equal. However, as long as the individual components of the basket "obey" the arbitrage argument and the consumption of the bundle does not change[4], the ratio between quantity of the domestic bundle that can be purchased with 1 EUR and the quantity of the foreign bundle that can be purchased with the same amount of money should be constant:

$$R_t = \frac{E_t P_t^*}{P_t} = k \tag{3}$$

[3]Some researches have tested the validity of PPP using the Big Mac Index, or the Starbucks (tall latte index), published both by the Economist (http:www.economist.com).

[4]Montiel (2009:52-63)

where k is the ratio between the quantity of the domestic bundle and the quantity of the foreign bundle that can be purchased with 1 EUR.[5] Thus, if relative PPP holds then the R_t need to be constant reflecting the differences in measurement of price level across countries (i.e. the constant parameter k can differ from 1 but should be constant over time).

Both the absolute and relative forms of PPP focuses on the equalization of the relative changes in price levels, i.e. inflation rates in two countries, and currency exchange rate, such that:

$$\Delta e_t = \Delta p_t^* - \Delta p_t. \tag{4}$$

where Δ is the first difference operator and e_t, p_t, p_t^* are natural logarithms of E_t, P_t and P_t^*, respectively. Equation above (4) states that the percentage change in the nominal exchange rate is equal to the difference between the inflation rates in the domestic and the foreign country. For example, if inflation in Norway increases by 5% within a year and inflation in Germany increases by 2.5% in the same year, then the relative PPP would predict a 2.5% depreciation of the NOK against the EUR.

Since information on national price levels is normally available in the form of price indices rather than absolute price levels, absolute PPP may be difficult to test empirically. The analysis conducted in this paper will be concentrated on testing the relative form of PPP.

4 The Data

The data examined in this study are monthly observations for Denmark, Iceland, Norway and Sweden with a time span ranging from October 2000 to September 2014 (i.e. 168 observations).[6] There are three variables: domestic prices (P_t), foreign prices (P_t^*) and nominal exchange rates (E_t). The price levels, (P_t) and (P_t^*) are measured by CPIs.[7] The real exchange rate (R_t) is constructed using equation (1).

Testing for the PPP against the Eurozone is based on the argument that the European Union is the largest trading partner for Denmark, Iceland, Norway and Sweden. Especially important is trade with Germany, the Netherlands and France (Appendix A). Since Germany is the largest single economy within EU, I chose to use the CPI for Germany as the foreign price. Each of the CPI and nominal exchange rate series was transformed into natural logarithms before the econometric analysis.

[5] Absolute PPP implies relative PPP, but not vice versa (Taylor and Taylor, 2004).

[6] All data are taken from Datastream.

[7] Because relative PPP is focused on relative price changes, it requires using of price indices (P_t), (P_t^*) instead of price levels (Taylor and Taylor, 2004).

Majority of the research and analysis are performed using statistical software RStudio.[8] Microsoft Excel is also used to make some minor data preparations. This includes naming columns and converting the data format such that it is compatible with RStudio.

4.1 Descriptive Analysis

A summary of the statistics of real exchange rates is given in table below (1). We can see that the real exchange rates for all countries differs from 1 ($R_t \neq 1$). However, this is allowed by the relative form of PPP (equation 3), which states that R_t can differ from 1 but should be constant over time. For all four variables, the means and the medians are close to each other. This probably indicates that the series in the data set are slightly symmetric. The ISK/EUR with values varying from 27.12 to 53.12 and a relative standard deviation of 16.24% is the most volatile currency, whereas the DKK/EUR with values varying from 5.986 to 6.420 and a relative standard deviation of 1.75% is the least volatile currency. This is not surprising since Denmark maintains a fixed exchange rate policy vis-a-vis the euro area and participates in the European Exchange Rate Mechanism (ERM 2) at a central rate of 746.038 kroner per 100 euro with a fluctuation band of +/- 2.25%.[9]

Volatility in Norwegian and Swedish currencies against EUR is moderate, even though these two have the same monetary policy as Iceland, where the inflation target is used as the target for monetary policy (i.e. floating monetary policy). The inflation targets are 2.5% in Iceland and Norway, and 2% in Sweden. The inflation target of the Eurozone is maintained by the European Central Bank (ECB) with a target below, but close to, 2% over the medium term.[10]

Table 1: Summary statistics of the real exchange rates from 2000-2014 (EUR base)

	DKK	ISK	NOK	SEK
Mean	6.188	37.99	6.385	3.049
Median	6.125	36.72	6.408	3.018
Maximum	6.420	53.12	7.827	3.675
Minimum	5.986	27.12	5.750	2.768
RSD*	1.75%	16.24%	4.98%	5.57%

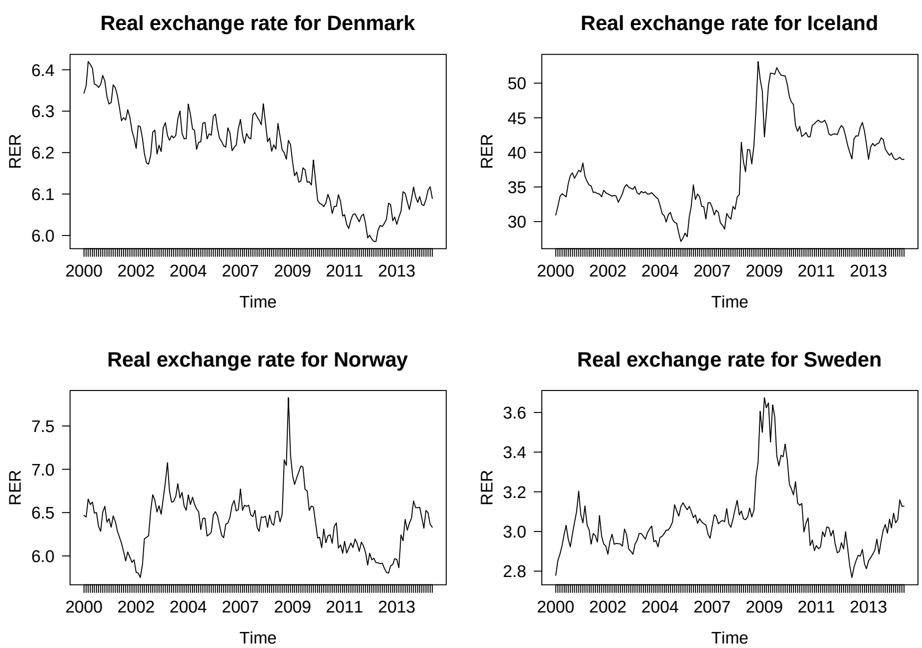
*Relative Standard Deviation is the absolute value of coefficient of variation in percentage and is calculated as follows: (std.dev./mean)∗100.

[8]http://www.rstudio.com
[9]Danmarks Nationalbank.
[10]The Central Bank of Iceland | Norges Bank | The Riksbank | European Central Bank.

The size of the trade in EUR can be some of the reasons behind the high volatility in ISK against EUR, compared with NOK and SEK. Appendix (A) clearly shows that the trade in EUR is less for Iceland compared with Norway and Sweden. High volatility in the real exchange rate for Iceland may also have accured as a result of a shock or several shocks in the economy, such as the financial crisis in 2008. In order to further analyze this, the time series for real and nominal exchange rates and CPIs are plotted.

Figure (1) plots the real exchange rate series for the four country pairs. The Danish real exchange rate appear to have downward trend movements over a longer period of time. As we can see, the real exchange for Denmark stand out with smoother movements in the exchange rates. The Danish fixed exchange rate policy against EUR is likely to be the reason behind it.

Figure 1: Real exchange rates, per EUR (2000-2014)



The R_t for Iceland, Norway and Sweden seem to fluctuate around a given level, without any persistent trends in one direction or the other. However, the plots of R_t for these three countries shows a spike in the exchange rates movement at the end of 2008/beginning of 2009. The 2008 financial crisis, which also contributed to the Eurozone crisis from early 2009, is most probably the cause of this shock in the data series for real exchange rate.

As can be seen, the real exchange rate for these three countries increased significantly between the end of 2008 and beginning of 2009 (i.e. an appreciation of the exchange rates against EUR). This spike in R_t was followed by a decrease and a long downward trend up to early 2013 as in the case of Norway and Sweden. The plots shows that from 2013 the R_t for Norway and Sweden returned back to a constant level.

The plot for Iceland shows several spikes in the R_t from 2008 to 2010, however, the Icelandic krona have not returned to a constant level prior to the financial crisis. The plot indicates that ISK against EUR received a new constant level after 2010. In econometrics, this kind of unexpected shift in a time series is often called "structural brake" or "regime shift", and can lead to forecasting errors and unreliability of the model in general (Brooks 2008:466).). This can be identified by several formal tests with studies of its own, however further elaborations will not be discussed in this paper since it is not part of this study.

In general, the exchange rates for Norway, Sweden and Iceland have experienced substantial fluctuations in periods and they do display rather long cycles. This indicates that deviations from any constant equilibrium level may last for several years.

Further, we can observe from the plot for Denmark that the real exchange do not vary about a fixed level, indicating non-stationarity in the mean but not in the variance, while the plots for Iceland, Norway and Sweden varies about a fixed level with constant variance, indicating non-stationarity in both the mean and the variance. This can be confirmed after testing for unit roots.

Figure 2: Development in the consumer price indices CPIs

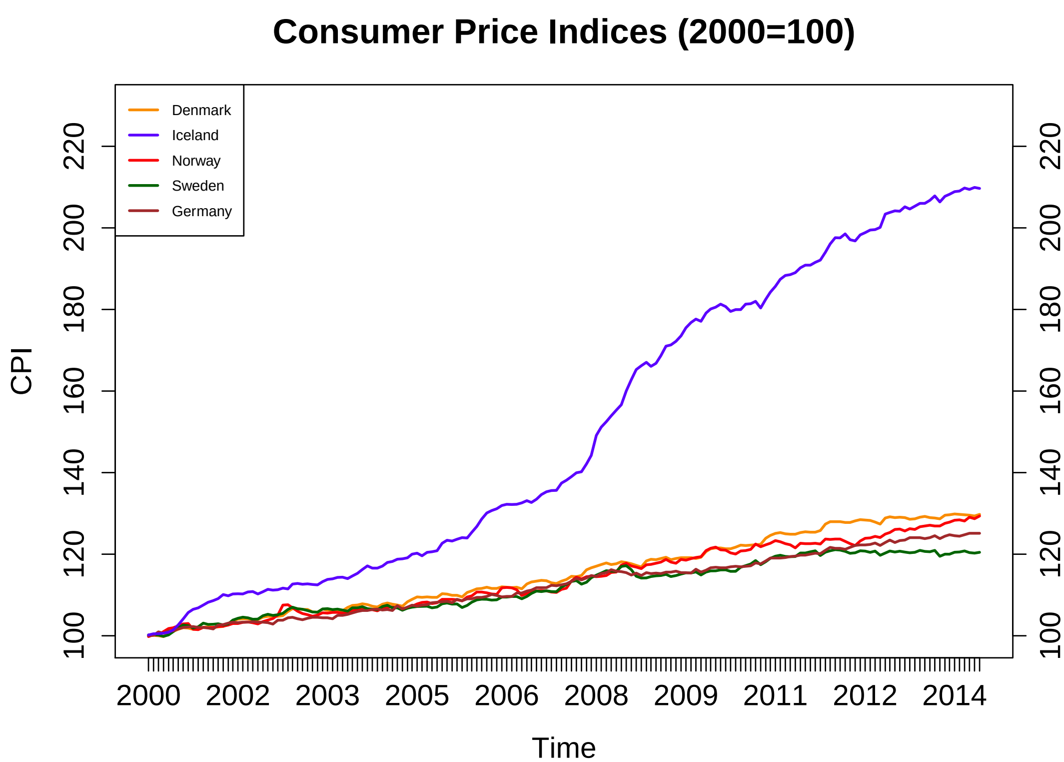


Figure (2) plots the CPIs for all five countries (including Germany).[11] The series are

[11]All CPIs are measured in national currencies.

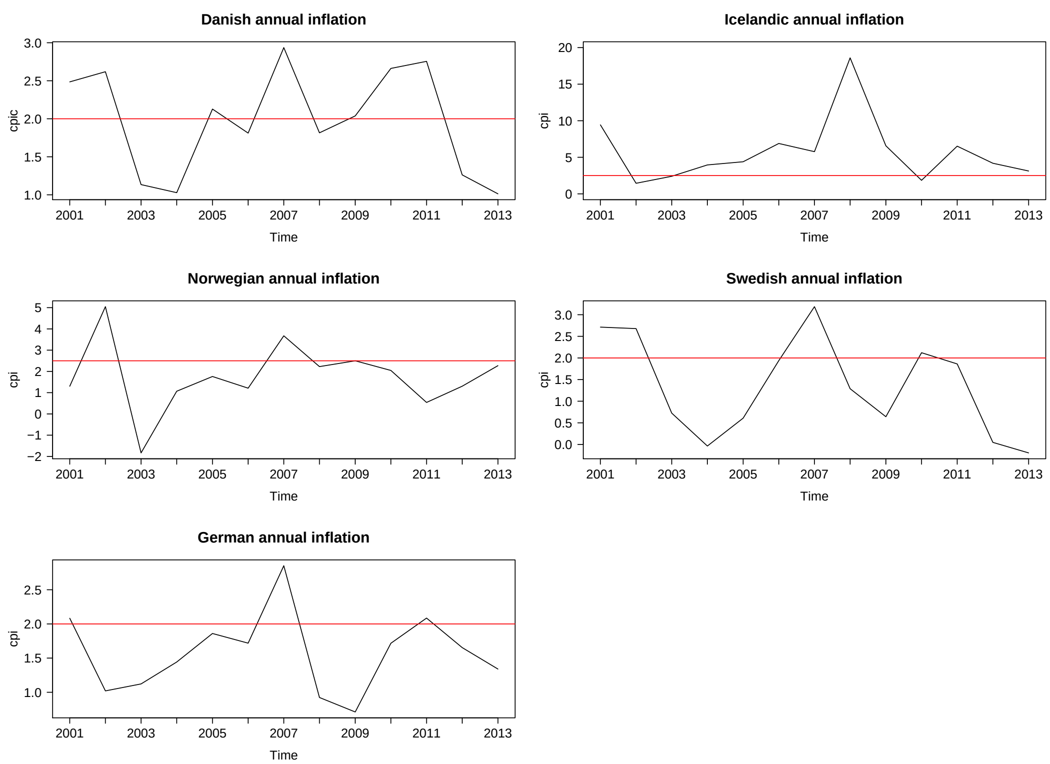
indexed (2000=100) in order to see the development in consumer prices (i.e. inflations) during the time frame of this study.

We can see that Iceland had a substantial higher increase in consumer prices with an average increase of 5.4% from 2000 to 2014 (a significant deviation from the Icelandic inflation target of 2.5%).[12]

The plot indicates a significant increase in inflation of consumer prices from 2008 to 2010. The ISK declined more than 35% against the EUR from January to September 2008. Iceland was among those Western countries that was hit hard in the onset of the global financial and economic crisis (Dapontas, 2013).

The relative consumer prices for Denmark, Norway, Sweden and Germany are fairly stable and move rather slowly with 1.9%, 1.9%, 1.3% and 1.6% average annual inflation rate, respectively.[13] However, these countries experienced unusual high price inflation in 2008 compared with previous years, with 3.4%, 3.8%, 3.4% and 2.6% respectively.[14]

Figure 3: Annual inflation (2001-2013)



Equation (5) states that changes in the nominal exchange rate and the relative consumer prices should outweigh each other if the parity condition in Equation (3) is holding. Considering the inflation in Icelandic prices we should expect a proportional change in

[12] The Central Bank of Iceland.

[13] $((CPI_{jT}/CPI_{j0})^{(1/n)} - 1) * 100$

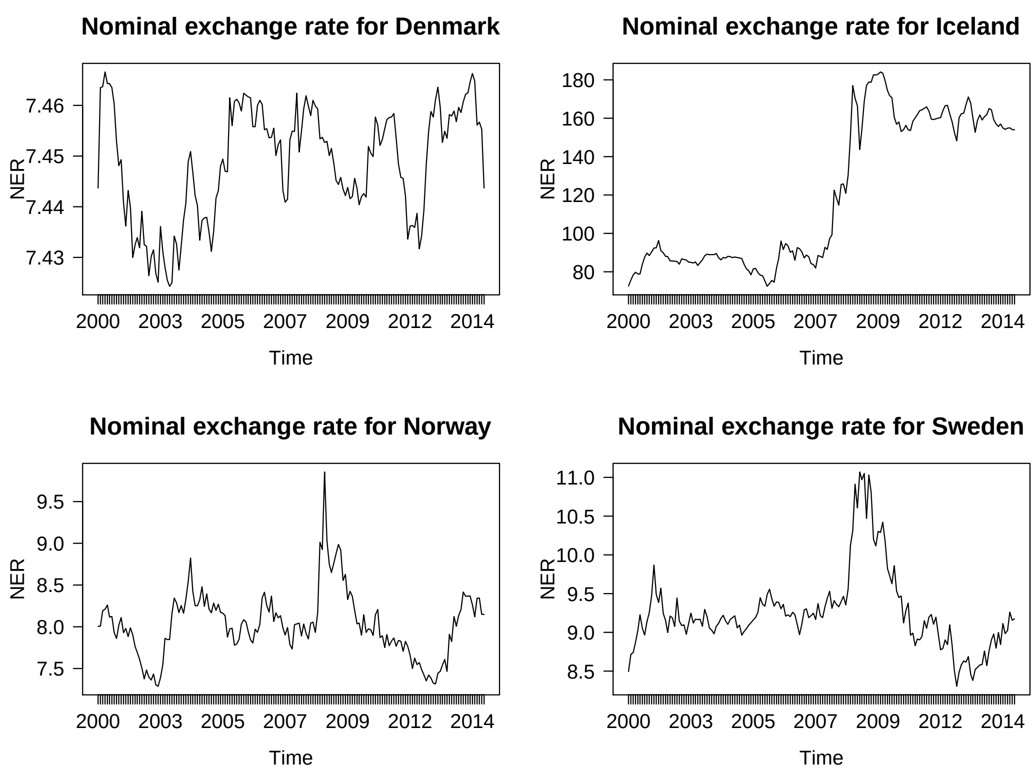
[14] The World Bank

the nominal exchange rate of Iceland (since the change in the price level of Germany (P_t^*) is "weaker").

Figure (3) illustrates the annual inflation from 2001 to 2013. In general, the annual inflation for all countries varies around their inflation targets (red lines). However, in the case of Iceland, the annual inflation has been higher than the target of 2.5% through the whole period. We can especially see a large deviation from its inflation target during the financial crisis. This again confirms the impact of 2008 financial crisis on Icelandic economy, and in this case, the consumer prices in Iceland (i.e. inflation). Otherwise, all countries have expereinced a higher inflation during the financial crisis.

Relative PPP implies that changes in national price levels (i.e. price indices) are offset by proportionate changes in the nominal exchange rates between the relevant currencies. From Figure (4) we can see a spike in 2008 in the nominal exchage rate for all countires. However, in the case of Icelandic krona, the nominal exchange rate have been fluctuating at almost the same level after the 2008 spike. This, as mentioned before, confirms a possibility of a "structural break" in the data series, and thus, a new constant level (from 2010 and on) for the Icelandic exchange rate against EUR.

Figure 4: Nominal exchange rates fluctuation (2000-2014)



Overall, from the visual observation of the time series behavior (exchange rates and prices), it is reasonable to assume that these variables are integrated in the long-run, meaning that the relative PPP hypothesis is holding.

5 Methodology

The graphical illustration of the domestic and foreign countries CPIs (Figure 2) tells us that these time series behave with an upward trend. The time series for nominal exchange rates (Figure 4) do not have any trend, but rather fluctuate around a given level (constant) over time. Thus, a formal test of stationarity (unit root), following Brooks (2008: 327-335), is applied.

5.1 Non-stationarity

Non-stationarity is a property common to many applied time series. A non-stationary series can be defined as one which does not have a constant mean, constant variance or constant autocovariances for each given lag. This means that a variable has no clear tendency to return to a constant value or linear trend. Often economic processes are generated by a non-stationary process and follow stochastic trends. One major objective of empirical research in economics is to test hypotheses and estimate relationships derived from economic theory, among other such aggregated variables.

It is necessary for the cointegration test that the order of integration of all the variables in the long-run will be the same.[15] Thus, the first step is to conduct a unit root test in order to determine that the time series behavior of the variables confirm the order of integration for our variables. There are several popular statistical tests to assess stationarity of data series. In this study the Augmented Dicky Fuller (ADF) test for unit root is applied.

The ADF test procedure in this paper consists of test regressions with two different combinations of the deterministic component. ADF model for testing the nominal exchange rates includes intercept/constant only:

$$\Delta e_t = \beta_1 + \psi e_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta e_{t-i} + u_t \tag{5}$$

where u_t is a pure white noise term. The lags of (Δe_t) "soak up" any dynamics structure present in the dependent variable, to ensure that u is not autocorrelated. The number of lags in the ADF test are obtained using the Akaike Information Criterion (AIC), to ensure that the errors are white noise.[16] The ψ=0 is equivalent to the existence of a unit root.

[15] The order of integration is the number of times, a time series variables must be difference for it to become stationary. If a non-stationary series, y_t must be differenced d times before it becomes stationary, then it is said to be integrated of order d, abbreviated as I(d) .

[16] The number of lagged difference terms to include is often determined empirically following the idea to include enough terms so that the error term is serially uncorrelated.

In order to test the unit root for CPIs the ADF model with both intercept and trend determenistic components is used:

$$\Delta y_t = \beta_1 + \beta_2 t + \psi y_{t-1} + \sum_{i=1}^{k} \alpha_i \Delta y_{t-i} + u_t \tag{6}$$

where y_t in our case is P_t or P_t^*. The β is the coefficient on a time trend series.

Under the null hypothesis of unit root $H_0 : \psi = 0$; the test statistics do not follow the usual t-distribution, but rather follow a non-standard distribution known as Dickey Fuller (DF) distribution. The test statistics for the original DF test are defined as:

$$t = \frac{\hat{\psi}}{S\hat{E}(\hat{\psi})}$$

If the test statistic is higher (in absolute value) than the critical value, the unit root hypothesis H_0 is rejected and it is concluded that the series is stationary. If we fail to reject the H_0, we assume that there is a unit root and the data series is not stationary.

5.2 Johansen Cointegration Test

The next step in our analysis is the specification of an initial, unrestricted VAR model that forms the basis for Johansen cointegration test. The framework of this section is mainly based on Brooks (2008: 335-365).

On the basis of the theory that integrated variables of order one, I(1), may have a cointegration relationship, it is crucial to test for the existence of such a relationship. If a group of variables are individually integrated of the same order and there is at least one linear combination of these variables that is stationary, then the variables are said to be cointegrated.

Johansen methodology for investigating cointegration in a multivariate system is commonly regarded as superior to the Engle-Granger method, particularly when the number of variables is greater than two (Johansen 1988, Johansen 1990).

The Johansen procedure is based upon a vector autoregressive (VAR) process for Y_t and with a maximum distributed lag length of k can be defined as:

$$Y_t = \Phi D_t + \Pi_1 Y_{t-1} + ... + \Pi_k Y_{t-k} + u_t \tag{7}$$

where Y_t is an (3×1) vector of variables $(E_t, P_t, P_t^*)'$ that are $I(1)$, D_t contains deterministic terms (constant, trend), Π_1 through Π_k are (3×3) coefficient matrices and u_t is the (3×1) vector of errors that is assumed independently and multinormally distributed.

The long-run relationships are captured in the coefficient matrix of Π. That is, if the rank of Π, denoted r, is between 0 and n, then there are r linear combinations of the variables in the system that are $I(0)$ or cointegrated.

The VAR in levels (Equation 7) can be transformed to a vector error correction model (VECM). Decomposing the polynomial matrix $\Pi(L) = \Pi(1)L + /Pi^{*}(L)\Delta$ where $\Delta \equiv (1 - L)$ is the difference operator, a (VECM) is obtained:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{i-1} + \Phi D_t + u_t \tag{8}$$

where Γ and Π are matrixes of variables, and lag length on each variable is now $k - 1$, since the dependent variables on the right-hand side are now expressed in the differenced form. The number of cointegrating vectors, are identical to the number of stationary relationships in the Π-matrix. If there is no cointegration, all rows in Π must be filled with zeros. If there are stationary combinations, or stationary variables, then some parameters in the Π-matrix will be non-zero.

The cointegrating matrix Π, which defines the long-term solution of the system, is defined as:

$$\Pi = -I + \Pi_1 + ...\Pi_k$$

where I is the 3×3 identity matrix in our case. This Π-matrix can further be decomposed into two $p \times r$ such that $\Pi = \alpha\beta'$. The $p \times r$ denotes the cointegration vector (β'=(1,-1,1)). The $p \times r$ matrix α is the matrix of error-correction coefficients which measure the rate each variable adjusts to the long-run equilibrium.

Since there are three variables in our system (E_t, P_t, P_t^*) in each case, and that the variables in their level forms are non-stationary, there can be at most two linearly independent cointegrating relationships for each country pair. Thus, with two cointegration vectors ($r = 2$) and the (3×2) $\Pi = \alpha\beta\prime$ matrix in our case, the Π-matrix can be decomposed as

$$\mathbf{\Pi} = \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \\ a_{13} & a_{23} \end{pmatrix} \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \end{pmatrix} \begin{pmatrix} E_t \\ P_t \\ P_t^* \end{pmatrix}_{t-k}$$

this can be writen as

$$\mathbf{\Pi} = \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \\ a_{13} & a_{23} \end{pmatrix} \begin{pmatrix} \beta_{11} E_t & \beta_{12} P_t & \beta_{13} P_t^* \\ \beta_{21} E_t & \beta_{22} P_t & \beta_{23} P_t^* \end{pmatrix}_{t-k}$$

Johansen proposes two different likelihood ratio tests, the "trace" test and "maximum eigenvalue" test, which are formulated as:

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{n} ln(1-\hat{\lambda}_i)$$

and

$$\lambda_{max}(r, r+1) = -Tln(1-\hat{\lambda}_{r+1})$$

where r is the number of cointegrating vectors under the null hypothesis and $\hat{\lambda}_i$ are the estimated values of the characteristic roots and also called Eigen values and T is the number of usable observation. The trace test tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of n cointegrating vectors. If r=0, it means that there is no relationship among the variables that is stationary.

The maximum eigenvalue test, on the other hand, tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of $r+1$ cointegrating vectors (Brooks 2008:351). The decision rule for both tests is: if the test statistic value is greater than the critical value than the null hypothesis is rejected.

6 Empirical Results

Results are divided in two parts. The first section illustrate results for ADF, where the stationarity of the data sereies is tested. The second section display findings from Johansen cointegration test.

6.1 ADF test

Table (2) presents results from ADF unit root test for both the nominal exchange rates and the price indices. The null hypothesis of unit root for nominal exchange rates at level form is accepted for all four countries. However, the test results for price indices shows mixed results where null hypothesis of unit root at level form is rejected for Denmark and Norway. This is somehow strange since graphical analysis of price indices did not reveal any substantial difference in growth for all countries except Iceland (Figure 2). Therefore the ADF unit root test should in theory give the same conclusion for these variables.

However, the deviation between the test statistics and critical values in both cases are marginal and gives an opposite conclusion at the 99% level. The lengh of the sample (i.e. 14 years) could be a reason for these results, which also includes a serious event

Table 2: ADF test results for nominal exchange rates and price indices

Variable	Deterministic terms	Lags[1]	ψ-values	Test values
DKK	constant	2	-0.08	-2.73*
ΔDKK	constant	2	-1.08	-9.68***
ISK	constant	2	-0.01	-1.14
ΔISK	constant	2	-0.87	-8.50***
NOK	constant	2	-0.09	-2.55*
ΔNOK	constant	2	-1.08	-9.06***
SEK	constant	2	-0.06	-2.17
ΔSEK	constant	2	-1.16	-9.80***
CPI^{DEN}	constant, trend	3	-0.15	-3.75**
ΔCPI^{DEN}	constant	2	-0.77	-10.10***
CPI^{ICE}	constant, trend	3	-0.01	-1.07
ΔCPI^{ICE}	constant	2	-0.31	-6.67***
CPI^{NOR}	constant, trend	3	-0.16	-3.94**
ΔCPI^{NOR}	constant	2	-0.82	-9.21***
CPI^{SWE}	constant, trend	3	-0.08	-2.58
ΔCPI^{SWE}	constant	2	-0.96	-10.33***
CPI^{GER}	constant, trend	3	-0.12	-2.73
ΔCPI^{GER}	constant	2	-0.94	-10.92***

Notes: [1]Number of lags are obtained using the Akaike Information Criterion (AIC) | ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. The 5% level is used as a benchmark in this paper.

(i.e. 2008 financial crisis) The ADF unit root test in known to have low power in the presence of "regime shifts" in the data sample (Brooks 2008: 466).

Another reason for the test results could be the number of lags chosen by the AIC method. The ADF test is very sensitive to the determition of the the optimal number of lags (k) of the dependent variable (y_t), and could be the reason behind our mixed results for unit root. Several ways of choosing k have been proposed by different reaserchers. The three most popular information criteria are Akaikes (1974) information criterion (AIC), Schwarzs (1978) Bayesian information criterion (BIC), and the Hannan Quinn criterion (HQIC). However, each of them have their advantages and disadvantages (which are not discussed here) and no criterion is superior to others (Brooks 2008:233). Thus, we accept the ADF test results given, by using the AIC criteria.

The Johansen cointegration test require that all variables in the test are integrated of the same order. In spite of these results, we proceed to the cointegration test because we assume that when variables with differing orders of integration are combined, the combination will have an order of integration equal to the largest (Brooks 2008:335).

In this paper a trivariate method to test the relative PPP hypothesis is used (i.e. E_t, P_t, P_t^*) and only one of these variables is different in the integrated form (i.e. P_t for Denmark and Norway). Thus, we assume that the sum of the combination of all three variables gives a form of integration equal to $I(1)$.

The ADF test is also performed with differentiated data and is applied the same way as before. The only difference is that variables are first differentiated once and then the test is applied. Conclusions are also made the same way as before. If a variable becomes stationary after its first difference, then the variable is said to be difference stationary or integrated of order $I(\mathrm{d})$ (Brooks 2008:326). The ADF test results shows that both nominal exchange rates and CPIs in the first difference form becomes stationary. The ψ-values have the right sign for all variables in both cases.

6.2 Johansen cointegration test

In Johansen test a two-stage testing procedure is implemented. In the first stage, the null hypothesis of no cointegration is tested against the alternative that the data are cointegrated with an unknown cointegrating vector (i.e. trace test). Under the second stage test the cointegration is maintained under both the null and alternative. The null hypothesis is that the data are cointegrated with the specific cointegrating vector implied by the PPP (i.e. maximum eigenvalue test). The results of applying Johansen trace and maximum eigenvalue tests are presented in Table (3).

The VAR model adopted here includes only a constant as the deterministic term, even though the CPI's series seems to have a long-term trend (Figure 2). The trend is restricted to the cointegration space to safeguard against invalid inference on the cointegration rank. (Doornik et al., 1998).[17]

The results show that the null hypothesis of no cointegrating vectors is rejected at 5% level of significance for all countries. Under the trace test the null of one or fewer cointegrating vectors ($r \leq 1$) is accepted for all countries except Iceland. In no cases the null of two or less cointegrating vectors ($r \leq 2$) is rejected. The null hypothesis of ($r = 1$) in the maximum eigenvalue test is accepted for all countries except Iceland. The null hypothesis of two cointegrating vectors ($r = 2$) is accepted for all countries. These results suggest that cointegration or long-run relationship between nominal exchange rates and prices does exist.

[17]The authors found that including an unrestricted trend was problematic and recommend the cointegration test with a linear trend restricted to the cointegration space and unrestricted constant.

Table 3: Johansen trace and maximum eigenvalues tests results

Null hypothesis	Alternative	Test statistic
Denmark		
λ_{trace} $(k = 4)$		
$r = 0$	$r > 0$	49.89***
$r \leq 1$	$r > 1$	17.89*
$r \leq 2$	$r > 2$	4.43
λ_{max} $(k = 4)$		
$r = 0$	$r = 1$	31.99***
$r = 1$	$r = 2$	13.46
$r = 2$	$r = 3$	4.43
Iceland		
$\lambda_{trace}(k = 4)$		
$r = 0$	$r > 0$	106.74***
$r \leq 1$	$r > 1$	30.37***
$r \leq 2$	$r > 2$	5.21
λ_{max} $(k = 4)$		
$r = 0$	$r = 1$	40.69***
$r = 1$	$r = 2$	21.00***
$r = 2$	$r = 3$	8.20*
Norway		
$\lambda_{trace}(k = 2)$		
$r = 0$	$r > 0$	52.90***
$r \leq 1$	$r > 1$	14.02
$r \leq 2$	$r > 2$	6.60
λ_{max} $(k = 2)$		
$r = 0$	$r = 1$	50.39***
$r = 1$	$r = 2$	11.56
$r = 2$	$r = 3$	6.40
Sweden		
$\lambda_{trace}(k = 4)$		
$r = 0$	$r > 0$	48.27***
$r \leq 1$	$r > 1$	12.14
$r \leq 2$	$r > 2$	4.37
λ_{max} $(k = 4)$		
$r = 0$	$r = 1$	36.13***
$r = 1$	$r = 2$	7.76
$r = 2$	$r = 3$	4.37

Notes: Number of lags (k) are obtained using the Akaike Information Criterion (AIC) | ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. The 5% level is used as a benchmark in this paper.

6.3 VECM-estimates

In this section, the estimation and testing of the cointegration rank in a VECM is implemented. The framework of this section is mainly based on Lütkepohl & Krätzig (2004: 115-143).

The coefficient estimates for all countries are represented below in the VECM loading matrices. Values in the parentheses are t-values. The first vector contains estimates for α, while the second vector contains estimates for β. The remaining part of matrices contain the autoregressive terms. For all countries we have r=1 and eigenvalues are normalised to the first column.

The result shows that for all countries except Sweden we do not find any support for the long-run relationship between nominal prices, as measured by CPI, and nominal exchange rates. This is very clear from the coefficient estimate of -0.17 with the t-value of -2.22 (the t-value has a correct sign as well).

Sweden:

$$\begin{pmatrix} \Delta E_t \\ \\ \Delta P_t \\ \\ \Delta P_t^* \end{pmatrix} = \begin{pmatrix} -0.01 \\ (-0.65) \\ -0.00 \\ (1.53) \\ -0.01 \\ (-5.33) \end{pmatrix} \begin{pmatrix} 1.00: & 1.42: & -1.06 \\ & (16.27) & (-14.01) \end{pmatrix} \begin{pmatrix} E_{t-1} \\ \\ P_{t-1} \\ \\ P_{t-1}^* \end{pmatrix}$$

$$+ \begin{pmatrix} -0.17 & 0.42 & 0.21 \\ (-2.22) & (-1.06) & (0.40) \\ -0.02 & 0.10 & -0.20 \\ (-1.35) & (1.72) & (-1.86) \\ -0.01 & 0.03 & -0.35 \\ (-0.88) & (0.52) & (-4.22) \end{pmatrix} \begin{pmatrix} \Delta E_{t-1} \\ \\ \Delta P_{t-1} \\ \\ \Delta P_{t-1}^* \end{pmatrix} + \begin{pmatrix} -0.08 & 0.47 & -0.46 \\ (-0.97) & (1.24) & (-0.85) \\ -0.02 & -0.26 & 0.43 \\ (-1.42) & (-3.28) & (3.90) \\ -0.03 & -0.17 & 0.03 \\ (-1.95) & (-2.84) & (0.31) \end{pmatrix} \begin{pmatrix} \Delta E_{t-2} \\ \\ \Delta P_{t-2} \\ \\ \Delta P_{t-2}^* \end{pmatrix}$$

$$+ \begin{pmatrix} 0.16 & -0.72 & 0.55 \\ (1.91) & (-1.84) & (1.02) \\ 0.01 & -0.22 & 0.42 \\ (0.37) & (-2.74) & (3.91) \\ -0.00 & 0.22 & -0.13 \\ (-0.36) & (3.57) & (-1.55) \end{pmatrix} \begin{pmatrix} \Delta E_{t-3} \\ \\ \Delta P_{t-3} \\ \\ \Delta P_{t-3}^* \end{pmatrix} \begin{pmatrix} \hat{u}_{1,t} \\ \\ \hat{u}_{2,t} \\ \\ \hat{u}_{3,t} \end{pmatrix}$$

Norway:

$$\begin{pmatrix} \Delta E_t \\ \\ \Delta P_t \\ \\ \Delta P^*_t \end{pmatrix} = \begin{pmatrix} -0.00 \\ (-0.29) \\ -0.00 \\ (-4.60) \\ -0.00 \\ (-6.23) \end{pmatrix} \begin{pmatrix} 1.00: & 8.81: & -9.66 \\ & (1.54) & (-1.48) \end{pmatrix} \begin{pmatrix} E_{t-1} \\ \\ P_{t-1} \\ \\ P^*_{t-1} \end{pmatrix}$$

$$+ \begin{pmatrix} -0.06 & 0.17 & -0.20 \\ (-0.71) & (0.54) & (-0.43) \\ -0.04 & 0.10 & -0.21 \\ (-2.46) & (1.28) & (-1.89) \\ -0.01 & 0.05 & -0.36 \\ (-0.87) & (1.07) & (-4.79) \end{pmatrix} \begin{pmatrix} \Delta E_{t-1} \\ \\ \Delta P_{t-1} \\ \\ \Delta P^*_{t-1} \end{pmatrix} + \begin{pmatrix} \hat{u}_{1,t} \\ \\ \hat{u}_{2,t} \\ \\ \hat{u}_{3,t} \end{pmatrix}$$

Denmark:

$$\begin{pmatrix} \Delta E_t \\ \\ \Delta P_t \\ \\ \Delta P^*_t \end{pmatrix} = \begin{pmatrix} -0.00 \\ (-0.10) \\ 0.16 \\ (2.66) \\ 0.30 \\ (5.39) \end{pmatrix} \begin{pmatrix} 1.00: & 0.09: & -0.12 \\ & (0.89) & (-0.99) \end{pmatrix} \begin{pmatrix} E_{t-1} \\ \\ P_{t-1} \\ \\ P^*_{t-1} \end{pmatrix}$$

$$+ \begin{pmatrix} -0.12 & 0.00 & 0.02 \\ (-1.51) & (0.12) & (0.97) \\ -0.74 & 0.26 & -0.06 \\ (2.02) & (3.30) & (-0.71) \\ 0.61 & 0.32 & 0.41 \\ (1.77) & (4.37) & (-5.10) \end{pmatrix} \begin{pmatrix} \Delta E_{t-1} \\ \\ \Delta P_{t-1} \\ \\ \Delta P^*_{t-1} \end{pmatrix} + \begin{pmatrix} -0.15 & 0.00 & 0.01 \\ (-1.83) & (0.05) & (0.55) \\ 0.02 & -0.26 & 0.65 \\ (0.06) & (3.53) & (7.12) \\ 0.55 & -0.17 & -0.05 \\ (1.57) & (-2.47) & (-0.64) \end{pmatrix} \begin{pmatrix} \Delta E_{t-2} \\ \\ \Delta P_{t-2} \\ \\ \Delta P^*_{t-2} \end{pmatrix}$$

$$+ \begin{pmatrix} 0.05 & -0.02 & -0.02 \\ (0.65) & (-1.43) & (-1.12) \\ -0.72 & -0.20 & 0.16 \\ (-1.92) & (-2.75) & (1.59) \\ 0.02 & 0.22 & -0.30 \\ (0.06) & (3.12) & (-3.24) \end{pmatrix} \begin{pmatrix} \Delta E_{t-3} \\ \\ \Delta P_{t-3} \\ \\ \Delta P^*_{t-3} \end{pmatrix} \begin{pmatrix} \hat{u}_{1,t} \\ \\ \hat{u}_{2,t} \\ \\ \hat{u}_{3,t} \end{pmatrix}$$

Iceland:

$$\begin{pmatrix} \Delta E_t \\ \\ \Delta P_t \\ \\ \Delta P_t^* \end{pmatrix} = \begin{pmatrix} 0.03 \\ (0.59) \\ 0.03 \\ (5.30) \\ -0.01 \\ (-2.69) \end{pmatrix} \begin{pmatrix} 1.00 : & -4.10 : & 12.87 \\ & (-15.95) & (6.08) \end{pmatrix} \begin{pmatrix} E_{t-1} \\ \\ P_{t-1} \\ \\ P_{t-1}^* \end{pmatrix}$$

$$+ \begin{pmatrix} 0.22 & -0.14 & -0.22 \\ (2.51) & (-0.20) & (-0.23) \\ 0.07 & -0.08 & 0.13 \\ (6.36) & (-0.97) & (1.13) \\ -0.00 & 0.06 & -0.43 \\ (-0.14) & (1.03) & (-5.43) \end{pmatrix} \begin{pmatrix} \Delta E_{t-1} \\ \\ \Delta P_{t-1} \\ \\ \Delta P_{t-1}^* \end{pmatrix} + \begin{pmatrix} \hat{u}_{1,t} \\ \\ \hat{u}_{2,t} \\ \\ \hat{u}_{3,t} \end{pmatrix}$$

7 Concluding Remarks

In this paper, the PPP hypothesis for four Nordic countries-Eurozone exchange rates and prices using data from 2000 to 2014 was tested. First, the augmented Dickey-Fuller test was applied in order to examine for the stationarity of data. The test indicated that the nominal exchange rates are non-stationary in their level form but stationary in their first differences. The stationarity test for price indices gave mixed results where the prices for Denmark and Norway showed to be stationary at their level form.

The study then applied the Johansen method of cointegration in order to determine whether there is any long-run relationship between spot exchange rates and prices for countries involved in the study. Johansen cointegration test showed the absence of a long-run relationship for all countries, except Sweden. Therefore, it can be concluded that the relative version of PPP holds in the long-run only for Sweden.

Moreover, the LOP does not apply to non-traded goods and the choice of an index in the empirical test can be essential. The CPI may be a ”wrong choice” of index since it includes a larger share of non-tradable goods than for example the WPI (Taylor and Taylor, 2004). Finally, the PPP hypothesis can be violated because of differences in the weights given to the different commodities in the construction of price indices.

The analysis performed in this study can be extended in order to exploit the implication of possible structural break(s) in the data. It is possible that the long-run relationships between the underlying variables change. The reason for this might be technological progress, economic crisis and policy or regime alteration. The 2008 financial crisis can be one of such shocks that can cause the change in the relationship between variables. The data series for Iceland in our case indicates such change.

There exists several formal tests which takes into consideration structural break(s) that could either confirm or deny the existence of one or several structural breaks in our data series. However, such tests are not part of this study and further studies can focus exactly on this aspect in order to either confirm or reject the empirical results from this study.

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Appendices

Appendix A

Table showing the trade for Denmark, Iceland, Norway and Sweden with Germany, France and Netherlands as well as the US for the last 10 years (both in numbers (in millions) and percentages). **Sources:** Statistics Denmark (http://www.dst.dk) | Statistics Iceland (http://www.statice.is) | Statistics Norway (http://www.ssb.no) | Statistics Sweden (http://www.scb.se)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total trade Denmark	798413,0	850441,2	928404,3	1039483,3	1080232,8	1137680,3	920754,5	1005124,6	1122922,0	1143215,3	1160364,5
Denamrk-France+Germany+Netherland	250478,0	260154,2	277118,2	304759,1	311277,2	327177,9	259899,0	277167,3	304212,1	306168,4	318519,5
Denmark-USA	38166,6	41543,9	46296,6	53135,9	53958,0	50915,4	46868,9	50436,0	52501,1	60170,9	54434,5
Denmark-France+Germany+Netherlands in %	31%	31%	30%	29%	29%	29%	28%	28%	27%	27%	27%
Denmark-USA in %	15%	16%	17%	17%	17%	16%	18%	18%	17%	20%	17%
In Euro (exch. rate 22.09.2014=7,44)	33666,40	34966,96	37247,07	40962,24	41838,33	43975,52	34932,66	37253,67	40888,72	41151,67	42811,76
Total trade Iceland	399104,7	418898,5	410880,4	459264,2	521620,9	683384,2	717379,6	777557,1	836652,7	849553,8	827216,4
Iceland-France+Germany+Netherland	105523,8	121274,2	131522,6	175840,8	201324,4	323753,1	311949,0	371721,3	413812,4	402984,1	378810,1
Iceland-USA	16927,3	18769,0	16299,2	26131,3	16049,7	25720,1	19402,9	25429,0	22959,1	28338,1	28667,3
Iceland-France+Germany+Netherland in %	26,4%	29,0%	32,0%	38,3%	38,6%	47,4%	43,5%	47,8%	49,5%	47,4%	45,8%
Iceland-USA in %	4,2%	4,5%	4,0%	5,7%	3,1%	3,8%	2,7%	3,3%	2,7%	3,3%	3,5%
In Euro (exch. rate 22.09.2014=154)	685,22	787,49	854,04	1141,82	1307,30	2102,29	2025,64	2413,77	2687,09	2616,78	2459,81
Total trade Norway	766202,0	880997,0	1026416,0	1194698,0	1264284,0	1457635,0	1161670,0	1255403,0	1407223,0	1442893,0	1434165,0
Norway-France+Germany+Netherland	211308,0	250454,0	289197,0	329744,0	341350,0	412181,0	320362,0	321994,0	357357,0	381435,0	422318,0
Norway-USA	56206,0	58189,0	61790,0	66632,0	71624,0	68042,0	61571,0	64655,0	77599,0	73315,0	68965,0
Norway-France+Germany+Netherland in %	28%	28%	28%	28%	27%	28%	28%	26%	25%	26%	29%
Norway-USA in %	7,3%	6,6%	6,0%	5,6%	5,7%	4,7%	5,3%	5,2%	5,5%	5,1%	4,8%
In Euro (exch. rate 22.09.2014=8,15)	25927,36	30730,55	35484,29	40459,39	41883,44	50574,36	39308,22	39508,47	43847,48	46801,84	51818,16
Total trade Sweden	1505100,0	1643400,0	1811100,0	2028900,0	2174200,0	2292300,0	1906500,0	2207400,0	2360200,0	2281600,0	2132700,0
Sweden-France+Germany+Netherland	371878,8	407920,3	441218,4	485989,6	537040,1	558130,2	465431,2	536298,6	567415,1	547157,8	522442,0
Sweden-USA	122009,5	122155,9	131125,1	132491,1	118777,4	112511,1	98820,4	117713,5	111853,0	110814,1	96425,7
Sweden-France+Germany+Netherland in %	25%	25%	24%	24%	25%	24%	24%	24%	24%	24%	24%
Sweden-USA in %	8%	7%	7%	7%	5%	5%	5%	5%	5%	5%	5%
In Euro (exch. rate 22.09.2014=9,17)	40553,85	44484,22	48115,42	52997,78	58564,90	60864,80	50755,85	58484,04	61877,33	59668,25	56972,96