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Habimana, Olivier

University of Rwanda, Jönköping University

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Olivier Habimana[a,b]

[a]Department of Economics, Finance and Statistics, Jönköping International Business School, Jönköping University, Jönköping, Sweden

[b]Department of Applied Statistics, College of Business and Economics, University of Rwanda, Kigali, Rwanda

E-mail: olivier.habimana@ju.se

Abstract

This paper investigates the extent to which macroeconomic fundamentals explain movements in the Swedish Krona against the Danish Krone and the Norwegian Krone exchange rates; three currencies of neighboring countries that are main trade partners and with long-term economic similarities. Exchange rates and fundamentals are decomposed into wavelet scales to gauge the explanatory power of the monetary model at different frequencies. There is a significant relationship between interest rate, inflation, and to a lesser extent the stock of money and output differentials and in-sample exchange rates movements at horizons of eight months and above. Wavelet decomposition uncovers the time scale aspect of exchange rate determination, and suggests that the monetary model is still a useful framework at medium and long horizons.

Keywords: Exchange rate disconnect puzzle, monetary model, Scandinavia, wavelets.

JEL codes: E44, F31

1 Introduction

For decades, it has been an empirical challenge to systematically explain exchange rates movements between floating currencies, what has been termed 'the exchange rate disconnect puzzle'. This puzzle has fueled the interest in the search for understanding the determinants of the swings in exchange rates. As pointed out by Rogoff (2001), not only do macroeconomic fundamentals fail to explain exchange rates, but it is not easy to systematically trace back the effects of exchange rates to economic fundamentals.

In two influential papers, Meese and Rogoff (1983 a, b) argue that available models of exchange rate determination cannot outperform the naïve random walk model[1]. The same had been mentioned earlier by Mussa (1979) who argued that spot exchange rates are random-walk processes, and most of the changes in exchange rates are unexpected. The fact that the simple random walk model performed better than any other structural model[2] came as a surprise, and has been since known as 'the Meese and Rogoff puzzle'. Furthermore, Rogoff (1999) points out that despite modern floating exchange rates, available long series and the application of more sophisticated methods, it is frustrating that the systematic relationship between exchange rates and fundamentals is yet to be uncovered. Frankel (1993) highlights that low R-squared, incorrectly-signed and insignificant coefficients are the main problems associated with the empirical performance of exchange rate models.

The structural approach to exchange rate determination has been dominated by the monetary approach of the 1970s. In the Keynesian tradition, the seminal work of Dornbusch (1976) emphasized the role played by the interaction of monetary shocks and sticky prices in explaining exchange rate fluctuations. Dornbusch's overshooting findings, i.e. in response to a monetary shock, the exchange rate overshoots its long-run value, seemed to imply that exchange rate movements could be predictable. Dornbusch's model has been since known as the sticky-price monetary model (SPMM). Outside the Keynesian tradition, Frenkel (1976) and later Bilson (1978a, b) proposed the flexible-price monetary model (FPMM), and argued that prices adjust instantly to clear the market. Frankel (1979) proposed the real-interest differential

[1] One tentative explanation has been that exchange rates follow random walks, and inherit this property from fundamentals. However, this explanation has been dismissed since it was found that fundamentals proposed in the most popular exchange rate models do not follow random walks (Engel and West 2004).
[2] Obstfeld and Rogoff (1995) in the framework of new open macroeconomics, challenged structural approaches and introduced the Redux model. The Redux model incorporates imperfect competition; prices are assumed to be sticky, at least in some sectors of the economy; and the optimization is done in the dynamic general-equilibrium framework.

model which is a hybrid of the SPMM and the FPMM. Sarno and Taylor (2002) provides ample literature on the evolution of exchange rate determination.

The ability of monetary models to predict exchange rates has been extensively investigated. Meese and Rogoff (1983a) empirically uncovered the inability of the structural models of Frenkel (1976), Dornbusch (1976), Bilson (1978a, b), Frankel (1979) and Hooper and Morton (1982) to predict exchange rates movements out of sample. These models were outperformed by a random walk model at a horizon of up to twelve months. Meese and Rogoff (1983b), in an attempt to explain the poor short-to-medium run forecasting performance, compare the random walk model to structural models at extended horizons of twelve to thirty-six months. They argue that the dismal performance of structural models cannot be attributed to inconsistent and inefficient parameter estimates, but rather to volatile time-varying risk premium, volatile long-run real exchange rates, or poor measurement of inflation expectations. Afat et al. (2015) argue that the invalidity of Keynesian money demand function is responsible for unfavorable results, and they suggest that a valid money demand function must be formulated. On the other hand, there are studies that have argued that the adjustment of the exchange rate toward its fundamentals might be nonlinear (Meese and Rose 1991; Taylor and Peel 2000; Ma and Kanas 2000; Kim et al. 2010). Furthermore, Bekiros (2014) argues that frequent variations in the relationship between exchange rates and macro-fundamentals in structural models can be attributed to parameter instability which may have little effect on exchange rate forecastability over short horizons, but is significant for long-run cointagrating relationships.

The rest of the literature can be categorized by the econometric methods applied. The first strand of literature has applied cointegration techniques to investigate the long-run relationship between exchange rate and fundamentals. Using panel cointegration methods, Groen, (2000), Mark and Sul, (2001) find evidence of the long-run relationship between exchange rates and monetary fundamentals. Groen (2000) argues that the failure to find a significant relationship in previous studies might have been due to low power of univariate cointegration tests. Similary, Rapach and Wohar (2002) find evidence of a significant long-run monetary model of U.S. dollar exchange rate against other industrialized countries. They argue that the monetary model performs poorly on a country-by-country basis, but panel cointegration tests largely indicate that US dollar exchange rates, relative money supplies, and relative income levels are cointegrated. MacDonald and Taylor (1994) employ cointegration techniques, and find evidence of a long-run relationship between exchange rate and fundamentals in a forward-looking monetary exchange rate model for the U.S. dollar/Deutsche Mark exchange rate.

However, Sarantis (1994) applies the same methods as Taylor, and fails to find evidence of long-run relationship.

The second strand of literature has employed long-horizon regressions. Mark (1995) argues that short horizons tend to be dominated by noise, which when averaged out over time it is possible to uncover the systematic relationship between exchange rate and fundamentals. They further find that forecasts improve with the forecasting horizon. The same conclusion was reached by Kilian (1999) who argues, however, that high predictability at long horizons might have been exaggerated by previous studies. Chen and Mark (1996) compare the ability of the purchasing-power parity, uncovered interest parity, and the flexible-price monetary model to predict nominal exchange rates. They find that monetary-model fundamentals appear to be the most robust predictors of long-run changes in nominal exchange rates. They further argue that at short horizons none of the fundamentals have significant predictive power.

The third strand of literature consists of studies that have applied wavelets. The literature in this category is scant and relatively very recent. Hacker et al. (2012) investigate the relationship between the Swedish krona (SEK) spot exchange rates against five major currencies. They decompose interest rates and spot exchange rates series using the DWT with Haar filter, and then apply regression analysis. They find that the relationship between the two variables is negative at shorter horizons, and positive at horizons over a year. Bekiros and Marcellino (2013) employ wavelet multiresolution analysis to investigate the dependence structure and predictability of the most trade currencies against the US Dollar. They find that interactions between currency markets have different characteristics at different timescales.

A bulk of the discussed studies have investigated the relationship between exchange rates and fundamentals mainly using the US dollar against other currencies. Mussa (1986) defines real exchange rate between two countries as the relative price of one country's consumption basket in terms of the consumption basket of the other country[3]. Owing to this definition, we investigate the relationship among countries that have similarities; countries that are main trade partners. According to Statistics Sweden, Norway and Denmark are respectively the third and the fourth trade partners (in terms of imports) of Sweden, after Germany and the Netherlands. Moreover, these are countries with very close consumer preferences, which implies relatively

[3] Real exchange rate might also be defined as the relative price of nontradable goods produced and consumed in that country in terms of tradable goods produced or consumed in that country. However, the use of this definition has been impaired by the lack of good measures of the relative prices of nontradables in terms of tradables (Mussa 1986).

similar basket of goods. Furthermore, unlike the traditional dichotomy of short and long-run, this study employs wavelets to decompose the series into different scales to capture the very short, medium and long-run dynamics of the relationship between exchange rate and fundamentals at horizons of two months to ten years. Wavelets are small waves with defined number of oscillations localized both in time and scale. For ample literature on the application of wavelets in economics, see Ramsey (2002), Gençay et al. (2002) and Crowley (2007), among others.

The timescale decomposition of exchange rate determination is motivated by several reasons. The foreign exchange market is diverse with different categories of traders operating and making decisions considering different time horizons. They range from the online hourly traders, the intra-day traders to the long-term traders. As pointed out by Hacker et al. (2012), regression analysis of wavelet decomposed series allows the coexistence of short-run relationships (with sticky prices) and long-run relationships (with flexible prices) between exchange rate and fundamentals. The wavelet transform serves as a zoom with different lens that allows to zoom the series in and out to capture the details. Moreover, wavelets have the ability to capture events that are local in time, making it possible to handle nonstationary time series. Nonstationarity implies that the relationships may vary by time scale, and requires some allowance for variation in the processes over time as well as for local effects (Ramsey and Lampart, 1998). Indeed some studies have suggested that the relationship between exchange rate and fundamentals is time-varying (inter alia, Sarno et al. 2004; Kim 2009; Chang and Su 2014).

This paper seeks to examine whether a wavelet decomposition of series can throw more light on the relationship between exchange rate and fundamentals in a monetary model. Wavelets can be viewed as 'lens' that enables the researcher to explore relationships that previously were unobservable (Ramsey 2002; Rua 2012). Unlike time-domain studies that use non-decomposed series which are made up of different layers of time effects, i.e. they include a mix of short-run, medium-run and long-run effects (Karlsson et al. 2016); wavelet-decomposition helps to restrict these effects at a given scale. The rest of the paper is organized as follows. Section 2 discusses the monetary approach to exchange rate determination. Section 3 presents data and describes econometric methods. Empirical results are presented and discussed in the fourth section. The last section concludes.

2 Theoretical Model

After the Flemming (1962) and Mundell (1963) model dominated in the 1960s, monetary models became the workhorse of exchange rate determination in the late 1970s. In the Keynesian tradition, the sticky-price monetary model (SPMM) originally developed by Dornbusch (1976) postulates that prices are rigid in the short run and adjust sluggishly to clear the market in the long run. Thus the exchange rate reacts to equilibrate money supply and money demand. On the other hand, in the flexible-price monetary model (FPMM) introduced by Frenkel (1976) and Bilson (1978a, b), and later revisited by MacDonald and Taylor (1994) and Flood and Rose (1995), prices adjust instantly to clear the money market. The real differential model by Frankel (1979) is a hybrid of Dornbusch and Frenkel models, and relies on the assumption that both the deviation from equilibrium of the current spot exchange rate and long-run inflation differentials determine the expected rate of depreciation of a currency.

The monetary model is derived from the following three blocks:

$$s_t = p - p_t^* \tag{1}$$

$$m_t - p_t = \beta y_t - \gamma i_t \quad \text{and} \quad m_t^* - p_t^* = \beta y_t^* - \gamma i_t^* \tag{2}$$

$$1+\mathrm{i}_t = \left[E\left(S_{t+1}\right)/S_t\right]\left(1+\mathrm{i}_t^*\right) \tag{3}$$

Where s, p, m, y and i are the price of domestic currency in terms of foreign currency, price level, the stock of money, output and the nominal interest rate, respectively. Except interest rate, variables are expressed in natural log. Asterisk denotes foreign country. $E\left(S_{t+1}\right)$ is the expected future value of spot exchange rate.

Eq. (1) is the relative purchasing power parity (PPP) condition—the change in the exchange rate reflects changes in the relative price levels of domestic vis-a-vis foreign goods. The PPP asserts that relative to the currency with the lower rate of inflation, the currency with higher inflation rate is expected to depreciate. Eq. (2) is the Cagan-type money demand function, which implies that money supply is exogenous and stable. Eq. (3) is the uncovered interest rate parity (UIP) condition, which is based on the assumption that domestic and foreign assets are perfectly substitutable[4].

[4] This assumption applies to the monetary approach in general. The alternative is the portfolio-balance approach that considers imperfect substitutability between domestic and foreign assets, see Frankel (1983) for comparison of the two approaches.

Taking log of Eq. (3)

$$\ln E\left(S_{t+1}\right)-\ln\left(S_t\right)+\ln\left(1+\mathrm{i}_t^*\right)=\ln\left(1+\mathrm{i}_t\right)$$

After rearranging,

$$\ln E\left(S_{t+1}\right)-\ln\left(S_t\right)=\ln\left(1+\mathrm{i}_t\right)-\ln\left(1+\mathrm{i}_t^*\right) \tag{4}$$

The UIP in Eq. (4) states that the expected depreciation equals interest rate differential.

Solving for s_t using (1) and (2) to get:

$$s_t = c+\alpha\left(m_t - m_t{*}\right)+\beta\left(y_t - y_t{*}\right)+\gamma\left(i_t - i_t{*}\right) \tag{5}$$

Assuming that the UIP holds, so that $r_t - r_t{*} = \ln\left(1+\mathrm{i}_t\right)-\ln\left(1+\mathrm{i}_t^*\right)$, Eq. (5) becomes:

$$s_t = c+\alpha\left(m_t - m_t{*}\right)+\beta\left(y_t - y_t{*}\right)+\gamma\left(r_t - r_t{*}\right) \tag{6}$$

Eq. (6) represents the FPMM attributed to Frenkel (1976) and Bilson (1978a, b).

Dornbusch (1976) argues that the assumption of price flexibility even in the short run is unrealistic, and suggests the sticky-price monetary model (SPMM) where prices adjust gradually, and the PPP holds only in the long run. Moreover, Frankel (1979) argues that the FPMM (also known as the ‘Chicago theory’ as opposed to the Keynesian tradition of sticky prices) is a realistic description when variation in the inflation differential is large. Frankel suggests the interest rate differential model which is a hybrid of the FPMM and the SPMM models, and hypothesizes that the exchange rate is negatively related to the nominal interest differential, but positively related to inflation differential. Empirically, Frankel suggests the following equation:

$$s_t = c+\alpha\left(m_t - m_t{*}\right)+\beta\left(y_t - y_t{*}\right)+\gamma\left(r_t - r_t{*}\right)+\delta\left(p_t - p_t{*}\right) \tag{7}$$

This model incorporates the short-run features of the Mundell-Flemming model, i.e. price stickiness, and allows short-term overshooting of exchange rates above their long-run equilibrium levels. To compensate for price stickiness in the goods market, exchange rates and interest rates act as ‘jump variables’ (Sarno and Taylor, 2002). Frankel’s model represents a realistic description of exchange rates movements when variation in the inflation differential is small (Frankel, 1979). Intra-Scandinavia Inflation differentials are depicted in Figure 7 in Appendix.

Table 1 summarizes different versions of the monetary model and the expected signs of the coefficients.

Table 1 Expected signs of monetary models' coefficients

Model	α	β	γ	δ
Frenkel (1976)	1	<0	0	>0
Bilson (1978a, 1978b)	1	<0	>0	0
Dornbusch (1976)	1	<0	<0	0
Frankel (1979)	1	<0	<0	>0

Source: Based on Frankel (1979), Frenkel and Koske (2004), and Bahmani-Oskooee et al. (2015)

3 Sample, data and methods

3.1 Sample and data

The sample covers the period from January, 1998 to December, 2014, a total of 204 monthly observations for each series. During this period both the SEK and the NOK have been (managed) floating. The DKK has been under a managed peg to the Euro since 1999, and is allowed to float inside a 'leeway' of 2.5%. Monthly (average and end of the month[5]) spot exchange rates of the Swedish Krona (SEK) against the Danish Krone (DKK) and the Norwegian Krone (NOK) were obtained from Sveriges Riksbank—the central bank of Sweden. Money supply (M1), index of industrial production (index 2010=100, a proxy for real output since we don't have data on the latter on a monthly basis), yields on 3-month T-bill, and consumer price index (a proxy for inflation) were retrived from the OECD's Main Economic Indicators database. Series are expressed in natural logarithm.

The econometric analysis follows two steps. First, the series are decomposed using wavelets, and then the model is estimated by feasible generalized least-squares (FGLS) at each wavelet detail.

[5] Figures 5 and 6 in appendix compare the average and end of the month exchange rates. The two almost coincide; end-of the-month SEK/DKK and SEK/NOK are therefore used in the analysis.

3.2 Wavelet multiscale decomposition

Most of the analyses in the economic literature have been done in the time domain. The frequency domain analysis was introduced in economic analysis in the 1960s in the effort to understand business cycles (e.g. Nerlove 1964; Granger 1969). Wavelets represent a refinement of the Fourier analysis. Wavelet analysis combines both the time and frequency domains. One of the strengths of the wavelets over other existing econometric methods is the ability to decompose the time series in several wavelet scales or frequencies. Wavelets provide both an orthogonal timescale decomposition of the data and a nonparametric representation of each individual time series (Ramsey, 1999). They offer the possibility to perform frequency decomposition of the series, and at the same time preserve the time location. The wavelet transform is able to capture all the information in the time series and associate it with specific time horizons and location in time (Gençay et al. 2002). Most importantly, the ability to capture events that are local in time, making it possible to handle nonstationary time series unlike the Fourier transform that is suited for series with time-invariant spectral content.

Following Ramsey (2002), it is possible to represent any function of time by the father (ϕ) and mother (ψ) wavelets. Father wavelets integrate to one, and are used to represent the very long scale smooth component of the signal. Mother wavelets, on the other hand, integrate to zero and represent the deviations from the smooth components. Father wavelets generate the scaling coefficients, while the mother wavelets generate the differencing coefficients.

The father wavelet is defined as:

$$\phi_{j,k} = 2^{-j/2}\phi\left(\frac{t-2^{j}k}{2^{j}}\right) \text{ with } \int \phi(t)\,dt = 1 \tag{8}$$

The mother wavelet is defined as

$$\psi_{j,k} = 2^{-j/2}\psi\left(\frac{t-2^{j}k}{2^{j}}\right) \text{ with } \int \psi(t)\,dt = 0 \tag{9}$$

In terms of frequencies, father wavelets are used for the lowest frequency smooth components, and mother wavelets are used for the higher frequency detail components. From the mother and the father wavelets one constitutes the basic functions from which a sequence of coefficients is defined:

The coefficients (smooth coefficients) of the father wavelets

$$s_{J,k}=\int f(t)\phi_{J,k}$$

The coefficients (detail coefficients) obtained from the mother wavelet

$$d_{j,k}=\int f(t)\psi_{j,k} \qquad j=1,...J \tag{10}$$

The maximal scale of the former is 2^j while the detailed coefficients are computed from the mother wavelets at all scales from 1 to J.

From the above coefficients, the function $f(.)$ is defined as follows:

$$f(t)=\sum_k s_{J,k}\phi_{J,k}(t)+\sum_k d_{J,k}\psi_{J,k}(t)...+\sum_k d_{j,k}\psi_{j,k}(t)...+\sum_k d_{1,k}\psi_{1,k}(t) \tag{11}$$

Which is simplified to:

$$f(t)=S_J+D_J+D_{J-1}+...D_j+...D_1 \tag{12}$$

With the following orthogonal components

$$S_J=\sum_k S_{J,k}\phi_{J,k}(t)$$
$$D_j=\sum_k d_{j,k}\psi_{j,k}(t), \quad \text{j=1,...J}$$

The resulting multiresolution decomposition of $f(t)$ is $\{S_J, D_{J-1},...,D_1\}$. D_j defines the jth level wavelet detail associated with changes in the series at scale λ_j. S_j is a cumulative sum of variations at each detail scale and becomes smoother as j increases.

In order to calculate the scaling coefficients and the wavelet coefficients, the maximal overlap discrete wavelet transform (MODWT) is employed. The MODWT is preferred over discrete wavelet transform (DWT). While the DWT of level J_o restricts the sample size to an integer multiple of 2^{J_o}, there is no such limitation for the MODWT, which is defined for any sample size (Percival and Walden 2000). The detail and smooth coefficients of a MODWT are associated with zero phase filters, which makes it possible to align features of the original time series with features in the multiresolution analysis, and the MODWT variance estimator is asymptotically more efficient than the DWT-based estimator (Percival and Mofjeld 1997; Gençay et al. 2002; Percival 1995). Moreover, while the DWT uses weighted differences and averages contiguous pairs of observations, the MODWT uses a moving difference and average operator, and thus keeps the exact amount of observations at each scale of the wavelet decomposition (Shukur et al. 2015).

The series are decomposed using the Daubechies—a family of compactly supported wavelet—least asymmetric (LA) filter of length 8. The LA (8) wavelet in Figure 1 is relatively smooth when compared with Haar wavelet filters (Gençay et al. 2002). Moreover, the LA(8) filter yields coefficients that exhibit better uncorrelatedness across scales than the Haar[6] filter (Cornish et al. 2006).

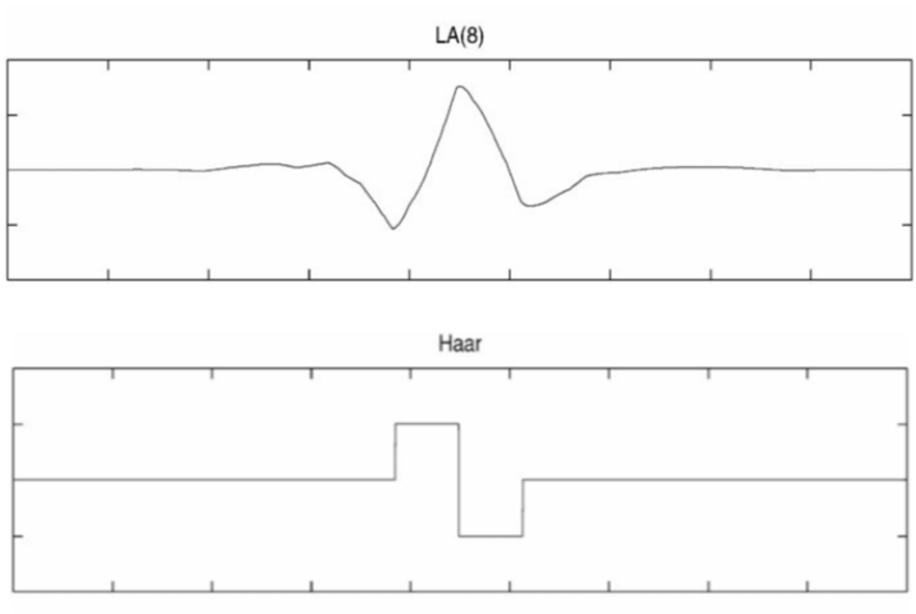


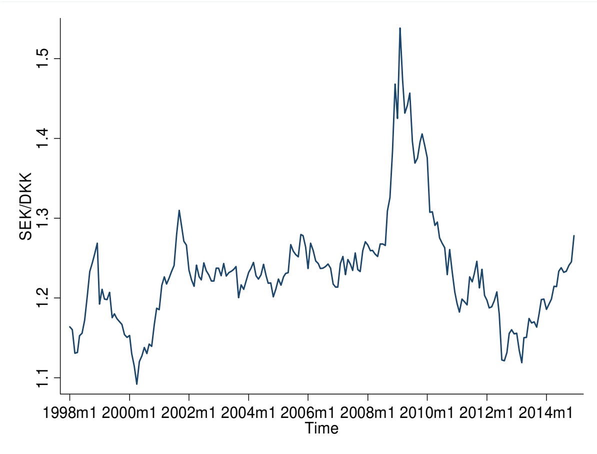
Fig.1 LA (8) and Haar wavelet filters

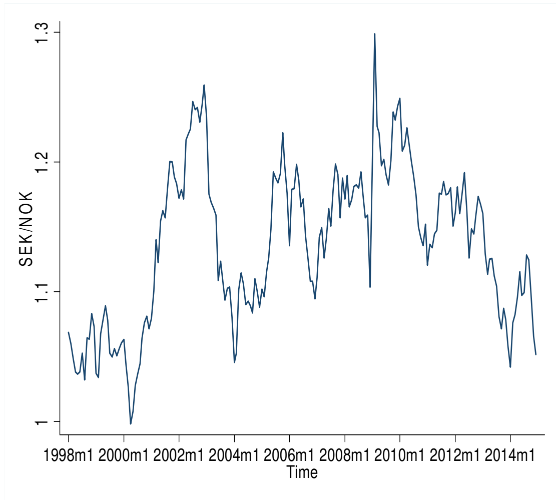
The series are decomposed into wavelets coefficient D_1 to D_6. The detail coefficient D_j provides a resolution of the data at scale 2^j to 2^{j+1}. The wavelet scales λ_1, λ_2, λ_3, λ_4, λ_5, λ_6 are associated with oscillations of periods 2-4, 4-8, 8-16, 16-32, 32-64, and 64-128 months, respectively.

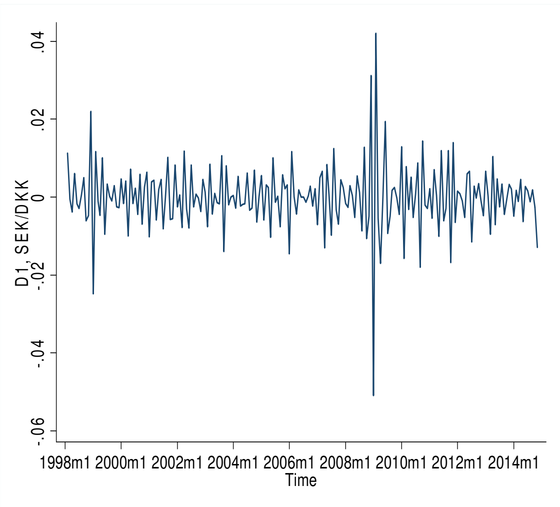
Figure 2 depicts the original series and their wavelet decompositions. To save space only exchange rates are presented. The two exchange rates exhibit high volatility across the period under study. Around the onset of the financial crisis and early 2009, the two exchange rates 'overshoot', and then the trend changes afterwards. This overshooting is very much reflected at lower scales (D1 to D3). The wavelet smooth S6 is hump-shaped. This shape clearly shows that

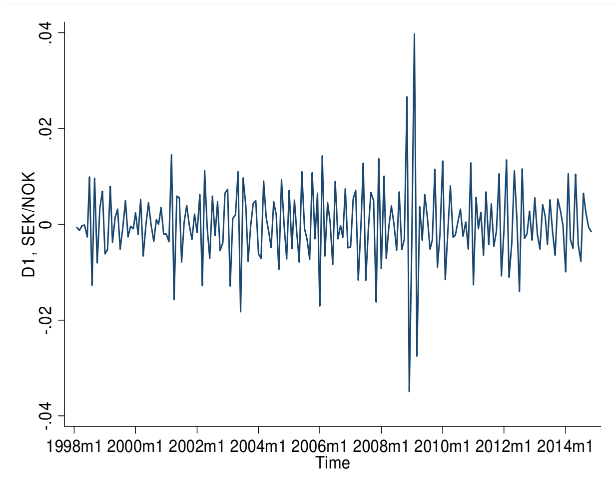
[6] The Haar filter is equivalent to Daubechies orthogonal wavelet D2. Haar filter is based on two non-zero coefficients, whereas LA(8) is based on eight non-zero coefficients. Since the number of vashishing moments(decay towards low frequencies) is given by the half of the length of the wavelet filter, Haar filter has one vanishing moment, while LA(8) has four vanishing moments which gives the LA(8) filter the ability to represent more complex functions than Haar filter.

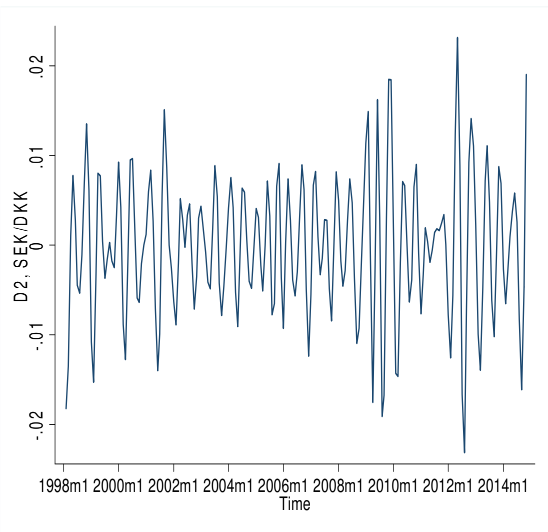
there has been a change after the financial crisis; the SEK appreciated against the DKK and the NOK. This highlights the ability of wavelets to uncover cycles and structural changes.

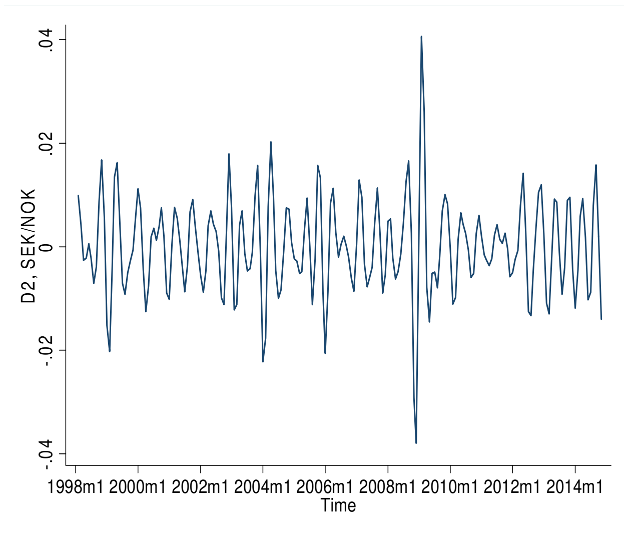


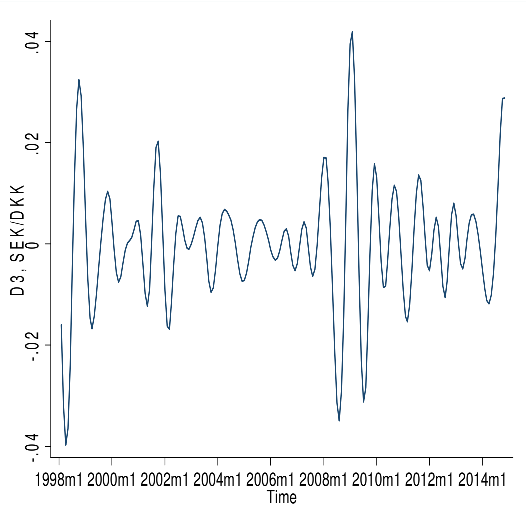


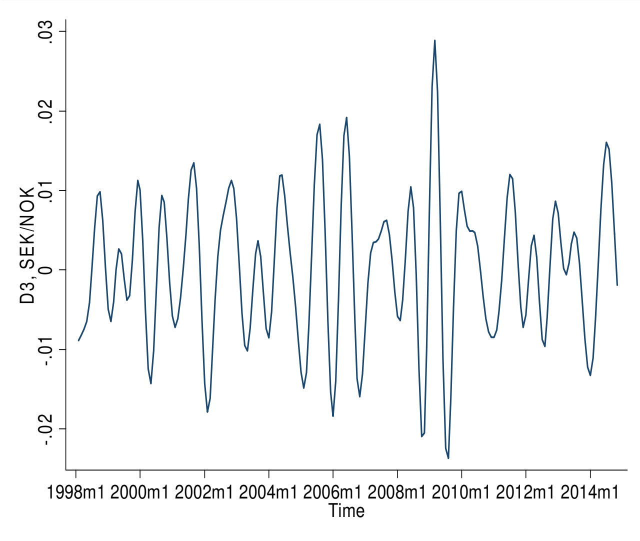


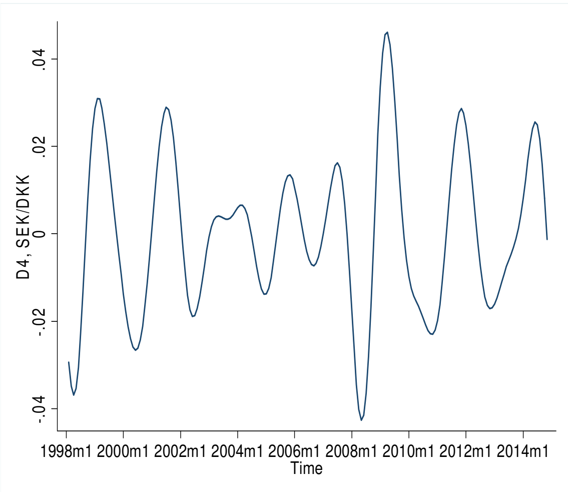


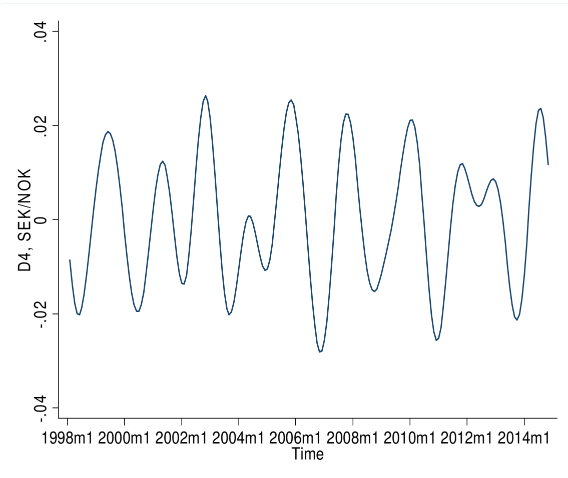


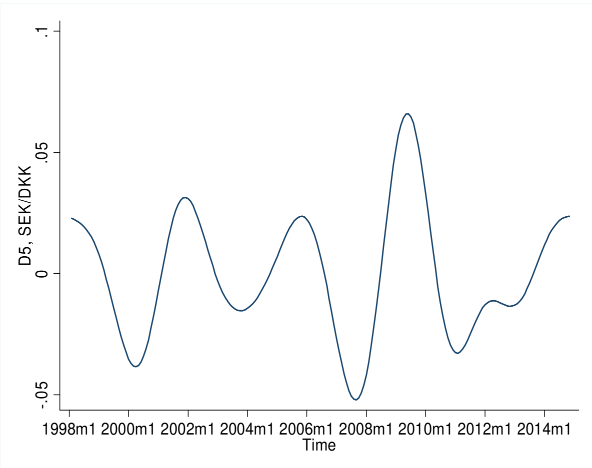


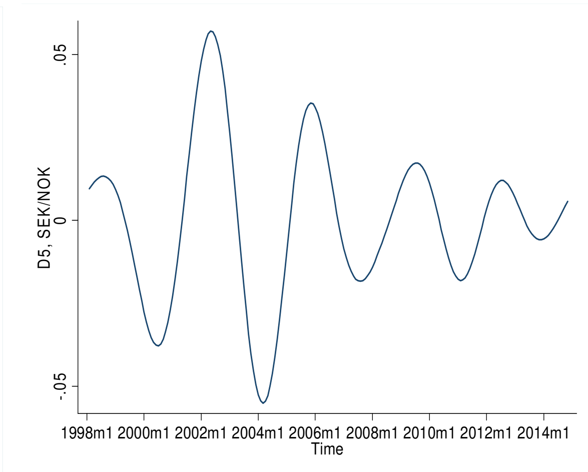

D3, SEK/DKK
Time


D3, SEK/NOK
Time


D4, SEK/DKK
Time


D4, SEK/NOK
Time


D5, SEK/DKK
Time


D5, SEK/NOK
Time

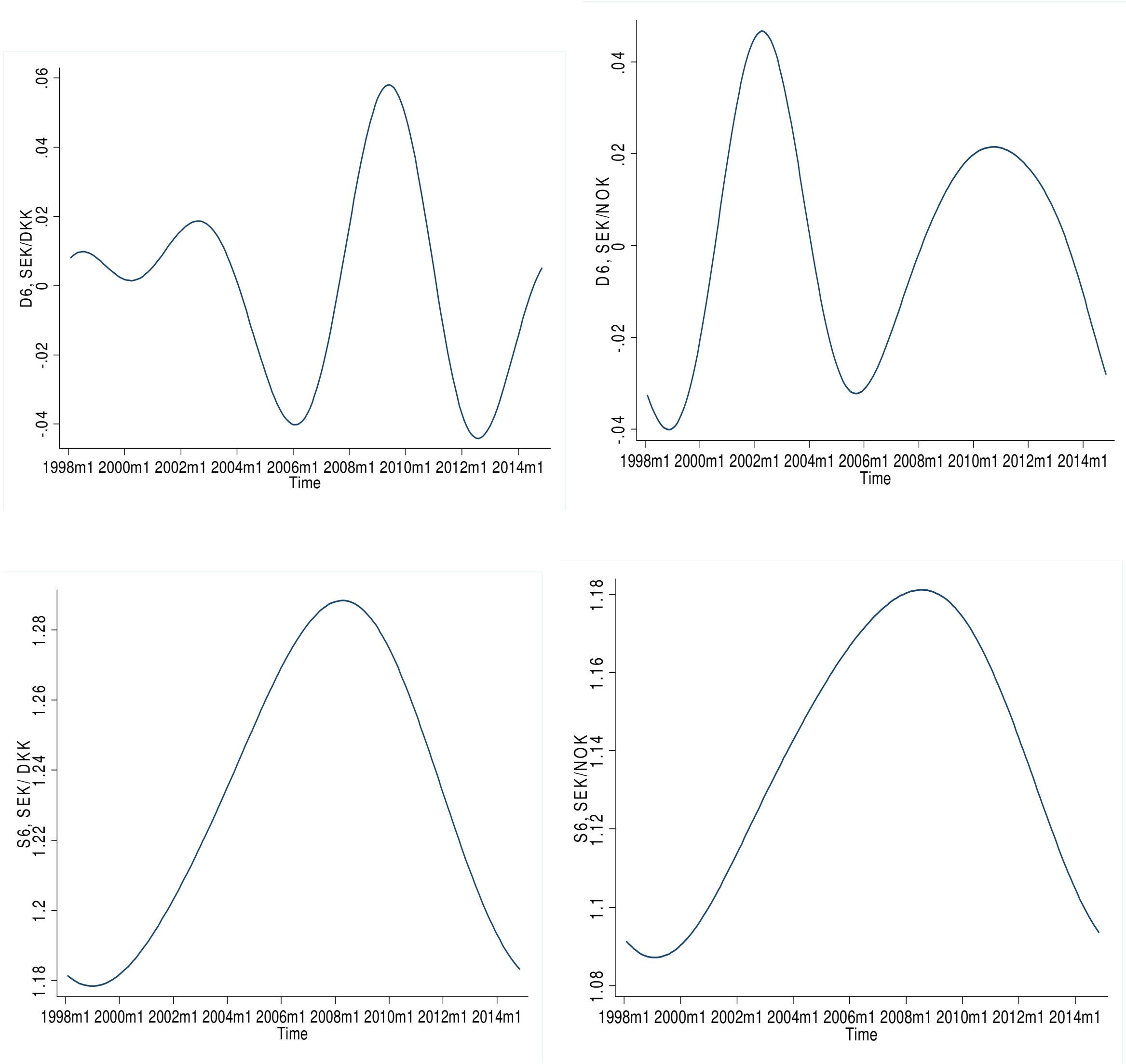


Fig. 2 MODWT LA (8) decompositions of SEK/DKK and SEK/NOK

Notes: The left panel plots the SEK/DKK exchange rate. The right panel plots the SEK/NOK exchange rate. First, raw series are plotted followed by wavelet details from D1 to D6 and the wavelet smooth S6 at the end.

3.3 Multiscale regression analysis

After decomposing the series, Eq. (7) becomes:

$$\ln S_t\left[d_j\right]_t = c_j + \alpha Mdiff\left[d_j\right]_t + \beta Ydiff\left[d_j\right]_t + \gamma Rdiff\left[d_j\right]_t + \delta Pdiff\left[d_j\right]_t + \mathrm{u}_{j,t} \qquad (13)$$

Where diff denotes differentials. d_j is the wavelet detail at scale j.

Before estimating Eq. (13), several time series issues need to be pointed out and handled to avoid potential spurious results. One advantage of wavelet methodology is that wavelet transforms turns the non-stationary series into stationary coefficients. However, we cannot take this property for granted especially at higher wavelet scales. Accordingly, to check the stationarity of the wavelet details, the null hypothesis of a unit root is tested employing the modified version of the Dickey–Fuller (DF) t-test as suggested by Elliott et al. (1996). The DF-GLS is more efficient, especially when an unknown mean or trend is present in the series. Alternatively the null hypothesis of stationarity is tested by Kwiatkowski et al. (1992) test, henceforth KPSS, against the alternative hypothesis of random walk. Both tests suggest that wavelet coefficients D1 to D4 are stationary[7] for all the series. As suspected, however, it turns out that most of D5 and D6 coefficients are not stationary. Since differencing the coefficients would result in loss of information and would undermine the very essence of wavelet methodology, we limit our regression analysis to the first four wavelet scales.

Moreover, the simple OLS[8] with robust (heteroskedasticity-robust) standard errors produced first-order serially correlated residuals at all scales except the second (4-8 months). Consequently, we employ the feasible generalized least-squares (FGLS) with Cochrane–Orcutt and Prais–Winsten transformations iteratively. When there is evidence of serial correlation, the FGLS is preferred to OLS; the FGLS estimator is more efficient and the FGLS test statistics are at least asymptotically valid (Wooldridge 2013, P.428). The gain in efficiency is remarkable especially in large samples.

4 Empirical results and discussion

Table 2 presents multiscale regressions based on wavelet-decomposed monthly series. At the finest scale (2 to 4 months), there is little predictive power for both SEK/DKK and SEK/NOK models. At the second scale (4 to 8 months), money stock becomes slightly significant with a positive sign for SEK/DKK and a negative sign for SEK/NOK. Inflation differential remains significant for both currency pairs but changes sign. Moreover, output differential has positive and significant coefficient for SEK/DKK. The R-squared also improves from almost 7 to 16 percent for SEK/DKK. The findings at the first two scales reiterate Chinn and Meese (1995), Flood and Rose (1995), Mark (1995) and Chen and Mark (1996) that fundamentals are unable to explain short-run exchange rate movements. At scales less than one year, we observe not

[7] The tests were performed for all the series and at all scales. To save space, results are not reported, but are available from the author upon request.
[8] The results are presented in Table 3 in the Appendix. Comparing the OLS and the FGLS results, although the overall interpretation does not change much, there are differences in terms of significance and goodness-of-fit.

only low goodness-of-fit, but also parameter instability. One tentative explanation, as previously pointed out by Mark (1995), short horizons tend to be dominated by noise. Moreover, traders in the foreign exchange and bond markets are more likely to be influenced by short-term market trends (Hacker et al. 2012).

The stock of money has opposite effect on SEK/DKK and SEK/NOK. While for the SEK/NOK the coefficients are negative, they are positive and significant for the SEK/DKK at the second (4-8 months), the third (8-16 months) and the fourth scale (16-32 months). The coefficients are nowhere close to unit as predicted by several versions of the monetary model (see Table 1).

The coefficients on output differentials are positive for the SEK/DKK and significant at the second (4-8 months) and the third (8-16 months) scales while they are negative for the SEK/NOK and significant at the third (8-16 months) and the fourth (16-32 months). The negative sign is what is predicted by several monetary models as summarized in Table 1.

At the third and fourth scales, the coefficient on interest rate differentials is negative[9] and very significant. Higher nominal interest rate in Sweden relative to Norway and Denmark results in an appreciation of the SEK currency against the NOK and the DKK. This consistent with the predictions of Dornbusch (1976) and Frankel (1979) models as opposed to Chicago (Frenkel-Bilson) tradition that hypothesizes a zero or positive coefficient on interest rate differential.

The coefficient on inflation differentials is positive and significant from the second scale (4-8 months). The positive sign implies that relatively high inflation in Sweden is associated with a depreciation of the SEK against the NOK and the DKK, which consistent with predictions of Frenkel (1976) and Frankel (1979) models as opposed to the Keynesian (Dornbusch) predictions.

Overall, these results, though using a different methodology, are in line with Mark (1995), Chinn and Meese (1995), and Chen and Mark (1996) who employ long-horizon regressions to investigate the predictability of several US dollar spot exchange rates by fundamentals. Similar to our findings, these studies agree with the traditional empirical studies (mainly Meese & Rogoff, 1988) that fundamental-based models have limited explanatory power in the short-run, but predictability improves with time horizon.

[9] In a recent paper, Engel (2016) argues that when a country's interest rate is high, its currency is appreciated not only because its deposits pay a higher interest rate, but also because they are less risky.

The variation in SEK/DKK explained by fundamentals is higher compared to that of SEK/NOK. One tentative explanation would be the role played by oil prices in the fluctuation of the NOK. Since Norway is the world's 7th largest oil exporter the NOK is a 'petrocurrency', and might be affected by fluctuations in oil prices. Empirical studies have documented that oil prices have significant explanatory power of exchange rates (see inter alia Chen and Chen 2007; Lizardo and Mollick 2010).

Table 2 Multiscale estimates of the monetary model

	SEK/DKK				SEK/NOK			
	2-4 (D1)	4-8 (D2)	8-16 (D3)	16-32 (D4)	2-4 (D1)	4-8 (D2)	8-16 (D3)	16-32 (D4)
c	-0.0000	-0.0001	-.0003	0.0002	0.0000	0.0000	0.0000	-0.0004
	(0002)	(0.0006)	(0.0013)	(0.0051)	(0.0002)	(0.0008)	(0.0016)	(0.0043)
α	-0.0029	0.1607***	0.1387***	0.2321***	-0.1041	-0.2784***	-0.2540***	-0.0978
	(0.0489)	(0.0384)	(0.0285)	(0.0481)	(0.0754)	(0.1065)	(0.0794)	(0.0767)
β	0.0404	0.117837***	0.1081*	0.1206	0.0616*	-0.0396	-0.2176***	-0.1434***
	(0.0311)	(0.0323)	(0.0523)	(0.0766)	(0.0321)	(0.0398)	(0.0440)	(0.0471)
γ	0.0094	-0.0302	-0.1451***	-0.1255***	0.0891**	-0.0163	-0.0947***	-0.0956***
	(0.0347)	(0.0284)	(0.0146)	(0.0094)	(0.0372)	(0.0262)	(0.0129)	(0.0122)
δ	-0.8429**	1.0097**	0.5633***	1.4210***	-0.4976**	0.4967**	0.4820***	0.1056**
	(0.3884)	(0.3033)	(0.2074)	(0.4195)	(0.2460)	(0.2056)	(0.1302)	(0.044)
R^2	0.0773	0.1607	0.5176	0.6203	0.0825	0.0599	0.2960	0.4466

Note: The regressions at each scale are based on the following equation $\ln S\left[d_j\right]_t = c_j + \alpha Mdiff\left[d_j\right]_t + \beta Ydiff\left[d_j\right]_t + \gamma Rdiff\left[d_j\right]_t + \delta Pdiff\left[d_j\right]_t + \mathrm{u}_{j,t}$.

Robust standard errors are in parentheses. ***, **, and * indicate statistical significance at the 10, 5, and 1% significance levels, respectively. The series are decomposed using the MODWT with LA(8) filter. Estimation is done by FGLS with Cochrane–Orcutt and Prais–Winsten transformations. As the estimation can be affected by outliers, the detail coefficients are truncated to remove the effect of extreme values at the endpoints of each scale.

5 Conclusion

This paper has sought to investigate the extent to which macroeconomic fundamentals explain intra-Scandinavian exchange rates. In order to investigate the explanatory power at different frequencies, series were decomposed by MODWT with Daubechies's LA (8) filter, then the FGLS with Cochrane–Orcutt and Prais–Winsten transformations was employed for estimation at each wavelet scale.

Our findings indicate a significant relationship between interest rate, inflation, and to a lesser extent the stock of money and output differentials and exchange rates movements at horizons of eighth months and above. At a horizon of 4 quarters, fundamentals explain around half of variations in intra-Scandinavian exchange rates.

Key to our findings is that higher nominal interest rate in Sweden relative to Norway and Denmark are associated with an appreciation of the SEK against the NOK and the DKK, and relatively high inflation in Sweden is associated with a depreciation of the SEK against the NOK and the DKK. These two findings are in line with the predictions of Frankel (1979)'s real interest differential model.

Finally, some caveats deserve mention. Although the Scandinavian economies are closely tied to each other, the link between oil price and the value of the Norwegian krone, and the peg of the Danish Krone to the Euro are other important factors that might influence movements in these bilateral exchange rates. Future research should therefore try to include these factors.

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Appendix

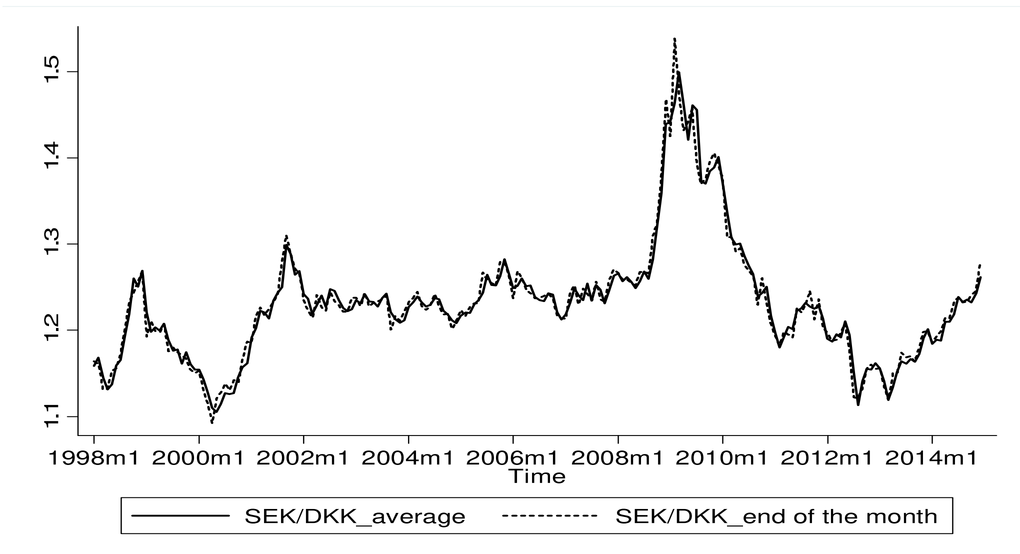

Fig. 5 SEK/DKK Exchange rate (average and end of the month)

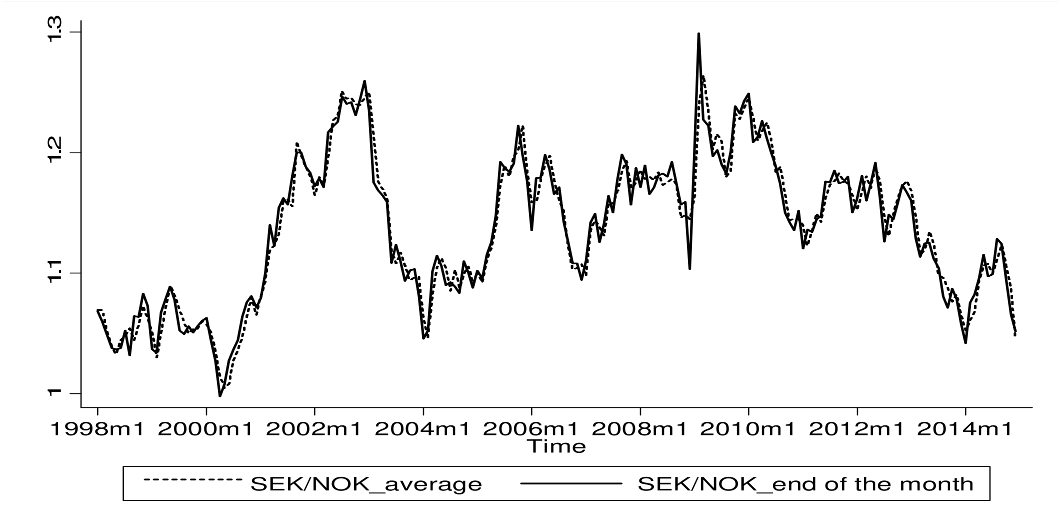

Fig. 6 SEK/NOK Exchange rate (average and end of the month)

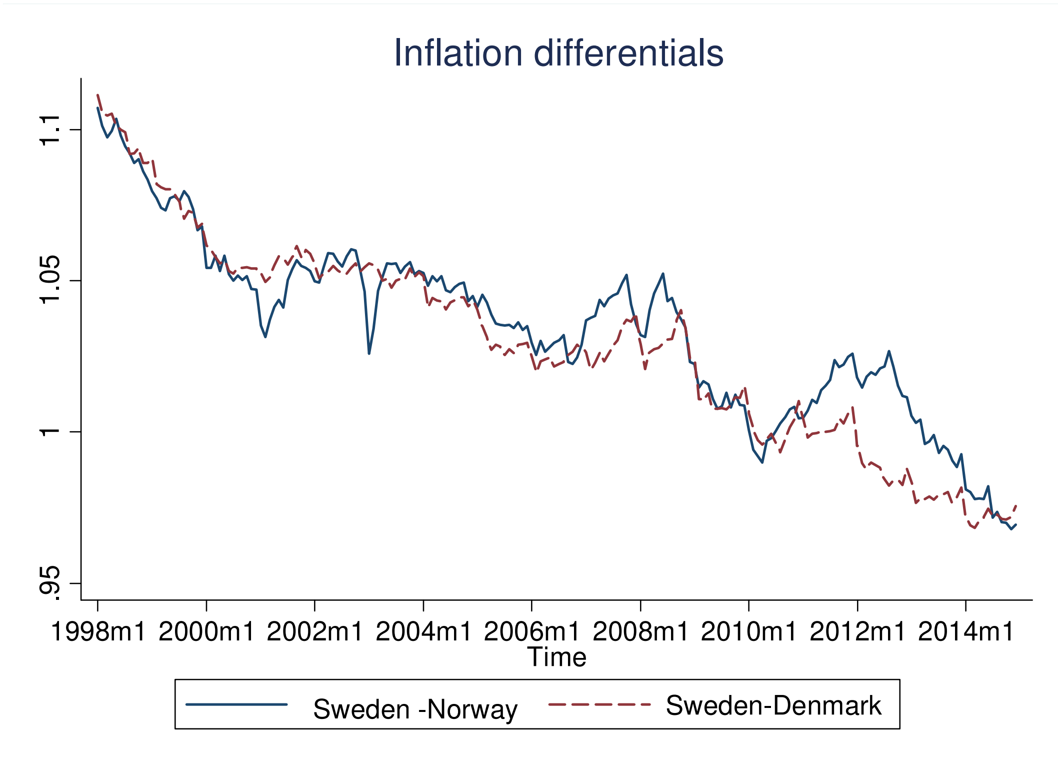

Fig.7 Inflation differentials

Table 3 Multiscale estimates (OLS)

	SEK/DKK				SEK/NOK			
	2-4 (D1)	4-8 (D2)	8-16 (D3)	16-32 (D4)	2-4 (D1)	4-8 (D2)	8-16 (D3)	16-32 (D4)
c	0.0000	-0.0001	-0.0001	0.0002	0.0000	0.0000	0.0001	-0.0001
	(0.0001)	(0.0002	(0.0003)	(0.0013)	(0.0001)	(0.0002)	(0.0003)	(0.0011)
α	0.0052	0.1691**	0.1335**	0.3599***	-0.0511	-0.3312*	-0.1414	-0.0623
	(0.0792)	(0.0691)	(0.0534)	(0.1197)	(0.0972)	(0.1789)	(0.1871)	(0.2131)
β	0.0149	0.1118**	0.0626	0.3395	0.0124	-0.0825	-0.2029**	-0.0893
	(0.0474)	(0.0500)	(0.1190)	(0.2578)	(0.0497)	(0.0556)	(0.0954)	(0.1025)
γ	-0.0121	-0.0468	-0.1491***	-0.1185***	0.0744	0.0267	-0.0947***	-0.1227***
	(0.0297)	(0.0476)	(0.0281)	(0.0201)	(0.0500)	(0.0267)	(0.0245)	(0.0258)
δ	-1.0727	1.1034*	0.5993	2.6303**	-0.3396*	0.4994**	0.3854*	0.2758
	(0.7787)	(0.5763)	(0.4612)	(1.1056)	(0.1775)	(0.2108)	(0.2316)	(0.3685)
Adj.R^2	0.0498	0.1830	0.6206	0.6232	0.0143	0.0745	0.2864	0.5005

Note: The regressions at each scale are based on the following equation $\ln S\left[d_j\right]_t = c_j + \alpha Mdiff\left[d_j\right]_t + \beta Ydiff\left[d_j\right]_t + \gamma Rdiff\left[d_j\right]_t + \delta Pdiff\left[d_j\right]_t + \mathrm{u}_{j,t}$. ***, **, and * indicate statistical significance at the 10, 5, and 1% significance levels, respectively. The series are decomposed using the MODWT with LA(8) filter. Estimation is done by OLS regression with Newey-West standard errors in parentheses.