Out-of-sample Performance of Taylor Rule Fundamentals and Traditional Models: SEK/USD during the Financial Crisis

Undergraduate Thesis

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ABSTRACT

This paper evaluates the ability of Taylor rule fundamentals and some traditional models over the period of the financial crisis. We use the Swedish Krona/U.S. Dollar exchange rate and quarterly data from 1993 to 2011, in order to compare the models' forecasting performance. Starting the analysis from the beginning of the financial crisis, the models' performance appears to be relatively inferior to the random walk. However, after the end of the Swedish recession, some positive results occur regarding Taylor rule models, which seem to outperform the interest rate differentials and other fundamental-based models against the random walk.

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1. Introduction

Since the early 1970s, international macroeconomics have struggled to find a relation between exchange rates and macroeconomics fundamentals. Despite exchange rates' high volatility, there is evidence that they are partly a reflection of fundamental-based models. Given that, international economists have been trying to analyze exchange rates dynamics hoping to find a better explanation about their movements, in comparison to finance economists regarding stock prices fluctuations. If so, this would have a tremendous influence on central banks' policy, which would manage to stabilize their economy via forex trading.

Nevertheless, exchange rates behavior has remained unexplainable by using economic fundamentals since "the Meese-Rogoff puzzle" (Meese and Rogoff, 1983). According to the puzzle, a good in-sample performance of structural models rarely conforms with a good out-of-sample performance. The latter is considerably affected by the forecast horizon, the choice of the model, the evaluation test and the data type. Some scholars have reported an enhanced forecasting performance at longer horizons, approximately two to four years[1].

Lately, there is an increasing number of studies which have found some forecasting power at more short-term horizons by applying new models. This is quite beneficial since horizons of one month to one year are more in parallel with policy implementation. Models based on Taylor rule fundamentals mainly appear to have great forecasting performance and exchange rates predictions. These models are constructed by assuming two economies which follow a Taylor rule (Taylor, 1993) in setting their interest rates. The Uncovered Interest Rate Parity (UIRP) founded by Fisher (1986), which is also based on relative interest rates, constitutes the core for these models despite appearing to have an inferior forecasting ability in most cases.

This paper implements Taylor rule as a structural fundamental similar to the research of Molodtsova and Papell (2009). We also compare the forecasting ability of the Taylor rule

[1]For instance, Meese and Rogoff (1983b), Engel, Mark and West (2007).

[2]Since the countries' trade is connected, fluctuations in commodity prices may explain some exchange rate movements.

fundamentals with the one of traditional models, such as the interest rate differential, in order to possibly prove the latter's lower performance. The significance of the out-of-sample forecast is evaluated by the DMW test, which is a common choice from the literature. The benchmark model used for the null hypothesis of the test is the random walk. Due to limited access, we use revised, instead of real-time, data which may deteriorate the performance of the models but still enforces our argument of choosing Taylor rule fundamentals. In essence, the type of data is not a restraining factor for Taylor rule fundamentals, like it is for monetary models (Rossi, 2013).

The Swedish Krona/U.S. Dollar (SEK/USD) exchange rate is the center of our analysis in order to examine the forecasting ability of the models during the financial crisis. The choice to elaborate on these currencies and this period of time is twofold. Firstly, there is limited research for the Taylor rule fundamentals during the financial crisis, especially for the SEK/USD exchange rate. We partly expand the analysis of Molodtsova and Papell (2009), since our paper includes the financial crisis, a period examined by Molodtsova and Papell (2012) but with different currencies. Secondly, Sweden and the United States are connected via imports and exports[2], thereafter the countries' close relationship may enhance the performance of the models. Namely, the United States is on the top five countries of Swedish trade balance.

The structure of the dissertation is the following; chapter two introduces literature review, which emphasizes on former analysis. Chapter three establishes the empirical framework, where some principles-terms are displayed and the methodology of the research is presented. Moreover, chapter four refers to the data used in this paper and chapter five contains the presentation of the results. Lastly, a conclusion in chapter six completes this thesis.

[2]Since the countries' trade is connected, fluctuations in commodity prices may explain some exchange rate movements.

2. Literature Review

The Meese-Rogoff puzzle constitutes a milestone in the behavior of the exchange rates based on economic fundamentals. Meese and Rogoff (1983) assessed the out-of-sample fit of various exchange rate models empirically with data from the 1970s. However, the naïve consistent change model surpassed the forecasting ability of the previous models, entailing the disconnection between macroeconomic fundamentals and exchange rates.

In the 2000s, there was a wave signifying the relationship between exchange rate predictability and Taylor Rule fundamentals. Among the first papers to encourage this connection was the one of Clarida, Gali and Gertler (1998), which recommends that the Taylor rule is a good reflection of the monetary policy. According to this assumption, they found out that Taylor’s Rule incorporation of the foreign real exchange rate vis-à-vis U.S. Dollar does not enhance nominal exchange rate predictability. Engel and West (2005) highlighted the discount factor convergence to unity, which induces a random walk behavior by the exchange rate comprised of the aggregate macroeconomic fundamentals. A substantial part of the literature[3] examines the Deutsche Mark/U.S. dollar (DM/USD) exchange rate and extracts noteworthy results. Engel and West (2004) create a model, which includes fundamentals as independent variables, researching this real exchange rate over the 1979-1998 period. They record low positive correlation between the model’s and the historical real exchange rate. According to Wan (2012), Engel and West (2004, 2005) constitute the first strand of literature.

The second strand of literature, developed by Mark (2009), provides information about the path of the same real exchange rate (DM/USD) with a model established on a learning framework from 1976 to 2007. The third strand of literature emerges from the analysis of Engel, Mark and West (2007). They supported the improvement of forecasting power with the installation of panel techniques in 18 currencies. Yet, the out-of-sample predictive power of the Taylor model was mildly average in both short (1 quarter ahead) and long (16 quarter ahead) horizons estimated. The hypothesis of similarity between countries’ Taylor rules (homogeneous) may have exacerbated the forecasting results (Wan 2012).

[3] Engel and West (2005) also include the DM/USD exchange rate in their analysis.

The fourth strand of literature is the foundation of my research and centres on Molodtsova, Nikolsko-Rzhevskyy and Papell (2008), Molodtsova and Papell (2009). The former, elaborate on a Taylor rule model with quarterly data for the DM/USD nominal exchange rate from 1979 to 1998. The use of inflation forecasts on their Taylor model rule does not reinforce the estimations for both samples, in contrast to the improved in-sample fit of the model with forecasts of output gap growth. They conclude that their model is significantly affected by the distinction between real-time and revised data. In essence, real-time data refers to the accessibility on information when the central banks determined the interest rate level and reflects the actual policy sufficiently (Orphanides, 2001). However, the reliance on revised data weakens their models' accuracy and deteriorates the rule's performance. Rossi (2013) contradicts that this data's differentiation impact is not that restrictive on the forecasting ability of Taylor Rule fundamentals. Molodtsova and Papell (2009) partly accept Rossi's claim and include "quasi-real time" for the creation of the output gaps. They report a strong evidence of short run out-of-sample predictability for 11 out of 12 countries vis-a-vis the United states from 1973 to 2006 by using Taylor Rule fundamentals.

Moreover, Molodtsova, Nikolsko-Rzhevskyy, and Papell (2011) follow a similar analysis to their previous paper in 2008, for the period of 1999 to 2007. Now, they find evidence of out-of-sample forecasting ability and exchange rate predictability between the U.S. Dollar and the Euro, based on Taylor rule fundamentals with real-time quarterly data. We could add in this strand the findings of Molodtsova and Papell (2012), which address out-of-sample exchange rate predictability with real-time quarterly data for the Euro/U.S. Dollar nominal exchange rate during different periods of the financial crisis. They create various Taylor rule specifications by embodying also credit spreads or financial condition indexes and notice that all these models outperform any other specification such as the interest rate differentials.

The last thread of literature encourages the application of semi-parametric interval forecasting for exchange rates. Namely, Wang and Wu (2012) follow this methodology for 10 OECD countries and conclude that, principally in the long run, the tightness of forecast intervals generated by Taylor rule models is superior to the one of the random walk. Empirically, Taylor rule models appear to outdo Purchasing Power Parity (PPP), monetary and forward premium models.

In this paper, we adhere to the fourth strand in order to test for the out-of-sample forecasting ability of Taylor rule fundamentals based on SEK/USD exchange rate. We include additional fundamentals and compare our models' results.

3. Empirical Framework

3.1 Taylor Rule Fundamentals

Taylor rule is a simple monetary rule which describes the nominal interest rate reaction of the central bank for fluctuations in inflation and the output gap. This backward-looking model has explained the actual behavior of the federal funds rate reasonably well. The original version of Taylor rule is expressed as follows:

$$i_t^* = \pi_t + \varphi(\pi_t - \pi^*) + \gamma y_t + r^* \quad (1)$$

In this equation, i_t^* reflects the target short-term nominal interest rate, π_t is the inflation rate, π^* is the inflation target level, y_t is the output gap or the divergence of actual Gross Domestic Product (GDP) from potential GDP and r^* is the equilibrium level of the real interest-rate.

In regard to Taylor rule, the monetary authority sets the nominal interest rate as a function of all these parameters specified above. An increase in inflation above its desired level or a positive output gap ensues a rise of the central bank's interest rate. A positive target level of inflation is a safety measure in order to prevent the much worse assumed deflation in comparison with a low inflation. The natural rate hypothesis states that the permanent exceedance of the actual output from the potential one is infeasible, hence the target level of the output deviation from its natural rate y_t is zero (Molodtsova and Papell, 2009).

Since the introduction of inflation targeting, the Swedish monetary policy almost always follows the Taylor rule equation. Jonsson and Katinic (2017) support the coordination between the Swedish monetary policy and Taylor rule since the effective application of inflation target from 1995. However, some shortcomings have emanated from the performance of Taylor rule. For instance, the rule does not allow for unexpected changes in the economy, such as the housing bubble of 2007. Molodtsova and Papell (2012) analyze the conversion from descriptive to prescriptive Taylor rules, by including measures of financial conditions which improve the performance of the Taylor rule models during the financial crisis.

The focal point of our analysis is to examine the relationship between a bilateral exchange rate and a set of fundamentals that are connected to the Taylor rule. According to Rossi (2013) the linear models are the most suitable for predicting the exchange rates. Thereby, we start with a linear Taylor rule which follows UIRP. The UIRP theory suggests that the difference in interest rates between two countries is equal to the expected change in the exchange rate over the same period (Dimand, 1999). Hence, UIRP is derived as:

$$(1 + i_{t+h}) = (1 + \tilde{\imath}_{t+h})\, E_t\left(\frac{S_{t+h}}{S_t}\right) \tag{2}$$

where E_t stands for the expectation at time t and ~ refers to foreign variables. The price of foreign currency in terms of domestic currency during period t is the nominal exchange rate S_t. The nominal exchange rate during period $t+h$ is denoted S_{t+h}, where h is the horizon and investors could buy $\frac{1}{S_t}$ units of foreign bonds using one unit of home currency, in a world of perfect foresight (Rossi, 2013). The foreign bond would pay one unit plus the foreign interest rate, hence the return converted back to domestic currency would equal $\frac{S_{t+h}(1+\tilde{\imath}_{t+h})}{S_t}$ in expectation.

Having considered arbitrage and lack of transaction costs, this return should be in expectation equal to the return of the home bond, which is $1+t$. By taking logarithms, the UIRP equation is modified as follows:

$$E_t(s_{t+h} - s_t) = a + \beta(i_{t+h} - \tilde{\imath}_{t+h}) \tag{3}$$

where s_t is in logarithmic scale, and the term $E_t(s_{t+h} - s_t)$ is the expected change in exchange rate. Two essential conditions for UIRP to hold, are the constant a must equal to 0 and the intercept b must be 1.

More specifically, we have two countries which set their interest rates based on Taylor rule, in a way that the exchange rate will be a depiction of their interest rates, inflation rates and output gaps (Rossi, 2013). The loadstar of Molodtsova and Papell (2009) leads us to a final model which indirectly excludes UIRP.

By rewriting equation (1), it appears that:

$$i_t^* = \mu + \lambda\pi_t + \gamma y_t \quad (4)$$

where the constant μ reflects the similar movement of the parameters π^* and r^* . We assume that $\lambda=1+\delta$ and $\lambda>1$ simultaneously in order to hold the Taylor principle.

By defining the real exchange rate as $q_t = s_t - p_t + \tilde{p}_t$ and adding it in equation (2), it yields:

$$i_t^* = \mu + \lambda\pi_t + \gamma y_t + \delta q_t \quad (5)$$

where q_t is the log of the real exchange rate, s_t is the log of the nominal exchange rate, p_t is the log of the American price level and $\tilde{p}_t$ is the log of the Swedish price level. Molodtsova and Papell (2009) explain the inclusion of the real exchange rate in the Taylor rule in order to make PPP hold. The central bank achieves that by setting the desired level of the exchange rate and raising the nominal interest rate if the exchange rate depreciates. CGG slightly modify the Taylor rule by letting for the partial adjustment of the interest rate to its target. Hence, we accept the assumption for the gradual interest rate adjustment to its desired level:

$$i_t = (1-\rho)i_t^* + \rho i_{t-1} + \nu_t \quad (6)$$

i_{t-1} represents the lag of the nominal interest rate it, while ρ reflects the interest rate smoothing parameter.

The substitution of (3) to (4) and the assumption that $\delta=0$ for the United States leads to the equation below:

$$i_t = (1-\rho)(\mu + \lambda\pi_t + \gamma y_t + \delta q_t) + \rho i_{t-1} + \nu_t \tag{7}$$

The creation of the interest rate differential is important, in order to construct the Taylor rule forecasting equation. Hence, we subtract the interest rate reaction function for the foreign country, from that of the domestic one:

$$i_t - \tilde{\imath}_t = a + a_{u\pi} + \pi_t - \alpha_{f\pi}\,\tilde{\pi}_t + \alpha_{uy} y_t - \alpha_{fy}\,\tilde{y}_t - \alpha_q\,\tilde{q}_t + \rho_u i_{t-1} - \rho_f\,\tilde{\imath}_{t-1} + \eta_t \tag{8}$$

where $\sim$ denotes foreign variables, u and f are subscripts for the domestic and foreign country. In our case, USA is the domestic country, while Sweden is the foreign country. Based on constant α, these apply to both countries: $a_\pi = \lambda(1-\rho)$ and $\alpha_y = \gamma(1-\rho)$. While for Sweden, we additionally have that $a_q = \delta(1-\rho)$.

We follow the Gourinchas and Tornell (2004) approach, like Molodtsova and Papell (2009) did, and conclude that the updating effect prevails the forward premium effect. The forward premium effect indirectly comes in line with Dornbusch's overshooting model. It begins with an increase in inflation above its desired level and its gradual reduction. This results to a similar movement by the interest rate. Assuming that the investors perceive the precise nature of the interest rate path, the appreciation of the exchange rate will stop until the interest rate differential is equal to the expected depreciation. Hence, in the long run UIRP holds.

The updating effect supports that UIRP does not hold neither short-term nor long-term. More particularly, investors now misjudge the duration of the interest rate increase and believe that it will return to its equilibrium level rapidly. This causes a moderate exchange rate appreciation. In the next period, the investors' expectations about the interest rate will remain lower than its actual value. Hence, the exchange rate will appreciate more due to the investors' beliefs update about the persistence of the positive interest rate shock. With the reveal of the true size of the shock, the exchange reverts to its equilibrium level.

These two terms were widely used by Molodtsova and Papell (2009) who find a strong link between higher inflation and forecasted exchange rate appreciation. Gourinchas and Tornell (2004), Clarida and Waldman (2008) show that an interest rate hike provokes to an immediate appreciation of the currency and a following forecasted appreciation of it. In other words, an upward trend in inflation creates expectations of tighter future monetary policy, which translates into currency appreciation for inflation-targeting countries[4]

Due to the updating effect dominance, UIRP does not hold, so we reverse the signs of the coefficients in equation (8) and derive the following exchange rate forecasting equation:

$$\Delta s_{t+1} = \omega - \omega_{u\pi} \pi_t + \omega_{f\pi} \tilde{\pi}_t - \omega_{uy} y_t + \omega_{fy} \tilde{y}_t + \omega_q \tilde{q}_t - \omega_{ui} i_{t-1} + \omega_{fi} \tilde{\imath}_{t-1} + \eta_t \qquad (9)$$

where the variable Δs_{t+1} represents the change in the nominal exchange rate. It is determined as the domestic price of foreign currency, so a decrease of it means dollar appreciation. The constant α has been replaced by ω, while ω's with subscripts are coefficients.

3.2 Assumptions and Specifications

Based on equation (8) and the fact that the central banks of the countries implement the Taylor rule, we make some predictions-assumptions:

[4]This relationship about inflation-targeting countries has been referred by Engel, Mark and West (2007), Rogoff and Rossi (2007).

1) The central bank of each country use the interest rate, based on the inflation target, in order to affect the positive link between inflation and forecasted exchange rate appreciation (Clarida and Waldman, 2008)

2) The central bank of each country will increase the interest rates, if there is a rise in their output gaps. Namely, the FED will increase interest rates provoking dollar appreciation, while the Swedish central bank will act similarly causing dollar depreciation.

3) The central bank of the foreign country will reduce the interest rates, if the real exchange rate for Sweden appreciates and it is embedded in central bank's Taylor rule, resulting to a dollar appreciation and Swedish krona depreciation.

4) A higher lagged interest rate will raise current and expected future interest rates, if interest rate smoothing exists.

There is a variety of models nested in equation (7):

1. *Symmetric or Asymmetric*: if the domestic country does not target the exchange rate, the equation is called symmetric ($\omega_q = 0$). Otherwise, we call the equation asymmetric because it includes the real exchange rate on the right hand side.
2. *Smoothing or No Smoothing*: if the interest rate does not fully adjust to its target level within the period, we create a model with smoothing. Otherwise, the lagged interest rate differential is missing from the right hand side ($\omega_{ui} = \omega_{fi} = 0$), meaning that the model has no smoothing.
3. *Homogeneous or Heterogeneous*: if the Swedish central bank and FED react exactly the same to macroeconomic shocks, regardless of the country where the shock emerges, and apply identical interest rate smoothing parameters, a homogenous model is developed ($\omega_{u\pi} = \omega_{f\pi}$, $\omega_{uy} = \omega_{fy}$, $\omega_{ui} = \omega_{fi}$). Alternatively, we call the model heterogeneous and the variables will enter the equation separately.
4. *Constant or No Constant*: if the countries regardless of having identical responses to alterations in inflation and output gap, also appear having the same inflation target rate and equilibrium real interest rates, we remove the constant from the equation (ω=*0*). Otherwise, the constant term is included in our model.

3.3 Traditional Models

Firstly, following UIRP, the expected change in the log exchange rate depends on the interest rate differentials between the countries. This leads to a rigid forecasting equation, where exchange rate movements conform with UIRP both in the short run and long run:

$$\Delta s_{t+1} = \alpha + \omega(i_t - \tilde{\imath}_t) \tag{10}$$

Empirical evidence indicates the usual inability of UIRP to hold in the short run, while the updating effect denies UIRP for any period of time. Consequently, we do not restrict ω and assume a possible consistency of the model with UIRP if and only if $\omega=1$ with a positive sign.

Secondly, following the PPP, the expected change in the log exchange rate equals the difference between domestic and foreign expected inflation rates. We form this model similarly to the previous one (unrestricted ω), since short run deviations tend to revert to PPP:

$$\Delta s_{t+1} = \alpha + \omega(\pi_t - \tilde{\pi}_t) \tag{11}$$

Lastly, the expected change in the log exchange rate equals the GDP growth rate differential. A rise in American GDP would raise import due to the income effect. This causes home currency to depreciate as home residents buy foreign currency to purchase imported goods. In the meanwhile, higher GDP would cause central bank to raise interest rate for stabilization. The high interest rate then attracts inflow of foreign currency which seeks for higher return in the international market. This would cause the home currency to appreciate. The model below includes both cases:

$$\Delta s_{t+1} = \alpha + \omega(y_t - \tilde{y}_t) \tag{12}$$

3.4 Benchmark Model and Forecast Evaluation

The article complies with the majority of literature and sets as a benchmark model the driftless random walk, which in accordance with Meese and Rogoff (1983) includes the best predictions of exchange rates. This indicates that if the exchange rate adheres to a random walk process, then yesterday's exchange rate is the best forecast of the today's exchange rate. Subsequently, the benchmark model is a zero mean martingale difference process, proposed by Clark and West (2006):

$$\Delta s_{t+1} = 0$$

Engel et al. (2007) report that the random walk without drift surpasses the forecasting performance of the random walk with drift. Thus, they find out that it is harder for various models, such as Taylor rule and PPP, to beat the former benchmark model in comparison with the latter one, at the one-quarter horizon. In general, literature appears to be in favor of the driftless random walk as the toughest benchmark model (Rossi, 2013).

Forecast evaluation comprises the choice of specific loss function in order to assess the forecast, and the choice of test for assessment of statistical significance. In regards to the former, researchers generally tend to measure out-of-sample forecasting performance of the models with root mean square forecast error (RMSFE):

$$RMSFE = \sqrt{\sum E[(s_{t+h} - \hat{s}_{t+h})^2]} = \sqrt{\sum[(\nu_{t+h})^2]}$$

In this equation, s_{t+h} and $\hat{s}_{t+h}$ refer to the actual and predicted exchange rate respectively, while ν_{t+h} is the error term. In order to evaluate the forecast precision of the models, we set as relative RMSFE the ratio of structural model RMSFE to benchmark model RMSFE. Hence, a ratio greater than one (relative RMSFE>1) would imply the random walk's forecasting dominance over the alternative model.

3.5 Out-of-sample performance

The majority of the literature emphasize on the out-of-sample forecasting ability of the Taylor rule fundamentals in comparison with the traditional economic predictors (Rossi, 2013). It is important to isolate predictability and forecasting ability since different tests are proper for each case (Rogoff and Stavrakeva, 2008). We focus on the out-of-sample forecast performance in order to "assess whether the predictors would have improved the exchange rate predictions in forecasting environments that mimic as closely as possible the one faced by forecasters in practice" (Rossi, 2013) and we use a rolling regression. The rolling estimation scheme, which includes the latest observation for forecasting, applies for predicting rather than the recursive estimation (Molodtsova & Ince, 2008). Also, it gradually mitigates parameter instability. We first divide the full sample, with size T+1, into an in-sample and an out-of-sample part. The former contains observations from 1 to R, where R is the estimation window size, and the latter consists of the remaining observations-predictions P in order to T+1=P+R. Progressively, a reestimation of the parameter happens, including the most recent R observations and keeping the size fixed. The process ends after all the out-of-sample observations are used. Rossi (2013) emphasizes on the influence of the window size to predictability for specific countries. The larger the estimation window is, the less the observations for out-of-sample forecast will be.

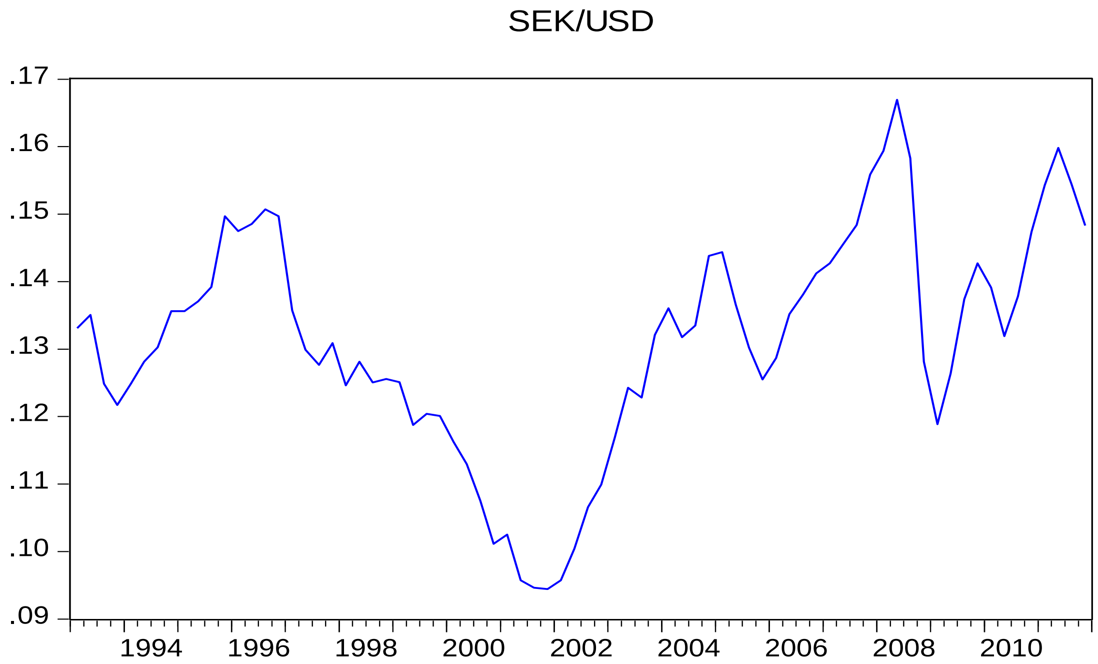
Rolling window scheme can enhance forecast accuracy compared to other windows for specific time series (Giacomini and White, 2006). We choose the test developed by Diebold and Mariano (2002) and West (1996), known as DMW test, in order to evaluate the forecast accuracy of our model. The DMW test evaluates the possibility of equal forecasting ability between two models. In particular, it measures whether the difference between the RMSFE of the structural model and the random walk is statistically significant (Stavrakeva and Rogoff, 2008). The null hypothesis demonstrates the equality of the Mean Squared Forecast Errors (MSFE) of these two models, meaning that their forecasts' accuracy level is the same. The alternative hypothesis indicates that the RMSFE of the two models are different, resulting in different levels of forecast accuracy. The DMW test is a hard test to beat which means that it tends to favor the random walk model because of its high level of significance requirement. Nevertheless, many scholars[5] argue disadvantages of the DMW statistic such as not following the normal distribution and being undersized.

4. Data Description

The currencies which we analyze are the U.S. Dollar and the Swedish Krona. The former as a home currency and the latter as a foreign currency. The analysis starts with the introduction of the Taylor in Sweden, so we use quarterly data from January 1993 to December 2011 for the estimation of the models. In the majority of the literature's models, the frequency of the data does not appear to have significant impact on the forecasts (Rossi, 2013). All the data for the construction of the models comes from the Federal Reserve Bank of St. Louis. We transform all the data using the logarithm function, except for the lagged interest rates.

We use Consumer Price Index (CPI), a measure of the price level in economy, in order to create the difference of the CPI as the inflation rate. The seasonal adjustment of the CPI for Sweden is done with the X-13 software. In order to create the lagged interest rates, we rely on the 3-Month London Interbank Offered Rate (LIBOR), based on U.S. Dollar and the 3-Month or 90-day Rates and Yields: Interbank Rates for Sweden. We use the real Gross Domestic Product (GDP) of both countries in order to form the output gaps. We consider as output gap the percentage deviations between actual output and the Hodrick Prescott (HP) trend. The smoothing parameter is set to 16000 (λ=16000) because of the quarterly data use.

[5] Molodtsova and Papell (2009), Stavrakeva and Rogoff (2008), Wan (2012) point out some significant disadvantages of the DMW test.



Notes: Presents the development of the SEK/USD exchange rate from 1993Q1 to 2011Q4.

The nominal exchange rate is defined as the U.S. Dollar price of one unit of foreign currency, so that an increase in the nominal exchange rate indicates an appreciation of the Swedish Krona. Swedish monetary policy, since the introduction of the inflation target in 2003, has been following the Taylor rule. In practice, however the inflation target began to apply during 1995. According to the graph, there is an all-time low in 2001Q4 which infers a major appreciation of the US dollar. The Dot-com bubble boosted the US economy and caused extreme growth. After the bubble, exchange rate gradually followed an upward trend due to the arrival of global financial crisis in late 2007. After significant fluctuations, exchange rate reached a peak in 2008Q2. The free float of the Swedish Krona and the large fiscal surplus reinforced the economy's recovery. During the recession in 2009, the Swedish Krona demand diminished due to the fall for Swedish products. This led to a strengthening of the commodity prices and a temporary drop of the exchange rate.

5. Empirical Results

There are total 20 models based on the specifications, referred to chapter three, including the Martingale process. The in-sample part or the period of estimation is 1993Q1-2007Q4 and the rest of the sample, namely 2008Q1-2011Q3, constitutes the out-of-sample part. This means that the first 60 observations are used for estimation and then one-quarter-ahead forecasts are constructed. Over time, we remove the first estimated observation of the in-sample and we re-estimate the parameters including the latest data. We also examine the impact of changes in the size of rolling window on the forecasting ability of the models. In order to measure the forecasting performance of the models, we incorporate relative RMSFE which is comprised of the RMSFE of each specification and the benchmark model (Martingale process).

5.1 Performance of the Taylor Rule Fundamentals

Considering either heterogeneity or homogeneity, there are in total 16 models. According to table 1, it is clear that no model outperforms the forecasting ability of the random walk. It is evident that models with homogeneous coefficients as a whole appear to have higher forecasting ability in comparison to those with heterogeneous ones. However, the best performing model is 8 which is formed on heterogeneous coefficients while constant, real exchange rate and interest rate smoothing parameters do not enter the equation. Despite its performance and regarding DMW-test, model 8 (as most of the models) does not have different levels of accuracy in comparison with the random walk.

	HERETOGENEOUS			HOMOGENEOUS		
	Relative RMSFE	**DMW-statistic**	**P-value**	**Relative RMSFE**	**DMW-statistic**	**P-value**
(1)Constant, Asymmetric, Smoothing	1.196665	1.2584	0.2288	1.092016	1.5906	0.1340
(2)Constant, Asymmetric, No Smoothing	1.138166	0.98516	0.3413	1.111486	1.5951	0.1330
(3)Constant, Symmetric, Smoothing	1.224439	1.3099	0.2113	1.131607	1.8398	0.0871
(4)Constant, Symmetric, No Smoothing	1.166379	1.1113	0.2851	1.134285	1.7129	0.1088
(5)No Constant Asymmetric, Smoothing,	1.209107	1.2752	0.2230	1.130149	1.7861	0.09574
(6)No Constant Asymmetric, No Smoothing,	1.163069	1.0856	0.2960	1.131282	1.6698	0.1172
(7)No Constant Symmetric, Smoothing	1.119436	1.2842	0.2199	1.086901	2.0842	0.05594
(8)No Constant Symmetric, No Smoothing	1.060855	1.1694	0.2618	1.083474	2.1758	0.04719

Table 1: This table shows the performance of all specifications of Taylor rule fundamentals during the financial crisis. It reports RMSFE, DMW-statistic and p-value for DMW test, between the null of martingale difference process and the alternative of a linear model with Taylor rule fundamentals. The models are estimated using data from January 1993 through December 2007.

On the other hand, models based on homogeneous coefficients create many statistically significant results in relation to DMW-test and have quite low RMSFE values, simultaneously. More specifically, models 3, 5 and 7 with homogeneous coefficients, forecast with different accuracy compared to the benchmark model, at 10% significance level. Both models 3 and 7 are symmetric and include interest rate smoothing, while the latter omits intercept. Model 5 is similar to model 7 but with asymmetric Taylor rule fundamentals. Model 8 with homogeneous coefficients develops different levels of accuracy relative to random walk, at 5% significance level. It has also the lowest relative RMSFE value after the same specification but with heterogeneous coefficients.

5.2 Performance of the Traditional Models

As illustrated in chapter three, we examine the forecasting ability of interest rate, PPP and output gap fundamental models. According to table 2, it is apparent that still any of these models either outperforms the forecasting ability of the random walk or ``creates statistically significant results. Nevertheless, the interest rate fundamental model seems to have the lowest relative RMSFE value in comparison to all the models analyzed. This slightly coincides with Ince, Molodtsova, Papell (2016) who found quite strong evidence of one-month-ahead predictability with interest rate model. They also reported no evidence of one-month-ahead predictability with the PPP model. In our case, PPP model turns out to have the lowest forecasting ability. The output gap model shows barely enhanced forecasting ability compared to PPP model.

	Relative RMSFE	**DMW-statistic**	**P-value**
Interest rate	1.047424	1.3034	0.2135
PPP	1.095501	1.0341	0.3186
Output gap	1.07321	1.6098	0.1298

Table 2: This table includes the traditional models' performance during the financial crisis. It reports RMSFE, DMW-statistic and p-value for DMW test, between the null of martingale difference process and the alternative of a linear model with Taylor rule fundamentals. The models are estimated using data from January 1993 through December 2007.

5.3 Rolling Window Sensitivity

According to literature, the forecasting ability of exchange rate models is directly connected with a variety of parameters. More specifically, the choice of forecast evaluation, data, benchmark model, horizon and sample period affect significantly the outcome. Giacomini and Rossi (2010) report that the choice of estimation time plays a cardinal role in the predictive ability of specific fundamentals, such as Taylor-rule, in relation with the random walk. In this section, we alter the size of the rolling window in order to test the sensitivity of our results. We consider a second out-of-sample period after the end of the recession in Sweden. This means that we increase our window size to 65 observations, namely until 2009Q1. Molodtsova and Papell (2012) note greater predictability in favor of all specifications of Taylor rule fundamentals compared to the random walk, during 2009Q2 and 2012Q1.

Table 3 includes the results of Taylor rule fundamentals, where the estimation period is 1993Q2 to 2009Q1 and the forecast evaluation period 2009Q2 to 2011Q3. According to DMW test, all models have the same level of forecasting accuracy with random walk. However, all models based on heterogeneous coefficients seem to outperform the forecasting ability of the benchmark model, in relation with relative RMSFE. More precisely, model 2 which is based on heterogeneous coefficients, constant, foreign exchange rate targeting but no interest rate smoothing, presents the best performance. Models based on homogeneous coefficients appear to have inferior forecasts compared to random walk. It is clear that there is considerable improvement in the forecasting performance of the models in terms of RMSFE, in comparison with the same specifications from 2008Q1 to 2011Q3.

	HERETOGENEOUS			HOMOGENEOUS		
	Relative RMSFE	**DMW-statistic**	**P-value**	**Relative RMSFE**	**DMW-statistic**	**P-value**
(1)Constant, Asymmetric, Smoothing	0.962580	-0.2917	0.7771	1.034065	1.0273	0.3311
(2)Constant, Asymmetric, No Smoothing	0.936963	-0.7318	0.4829	1.031280	0.67829	0.5146
(3)Constant, Symmetric, Smoothing	0.997786	-0.0134	0.9895	1.084152	1.3794	0.2011
(4)Constant, Symmetric, No Smoothing	0.974725	-0.2710	0.7925	1.066306	1.0234	0.3329
(5)No Constant Asymmetric, Smoothing,	0.992194	-0.0460	0.9643	1.080097	1.2924	0.2284
(6)No Constant Asymmetric, No Smoothing,	0.973513	-0.2823	0.7841	1.061714	0.95363	0.3652
(7)No Constant Symmetric, Smoothing	0.944010	-0.4935	0.6334	1.083192	1.5108	0.1651
(8)No Constant Symmetric, No Smoothing	0.972349	-0.3020	0.7695	1.067178	1.0474	0.3222

Table 3: This table shows the performance of all specifications of Taylor rule fundamentals after the end of the Swedish recession. It reports RMSFE, DMW-statistic and p-value for DMW test, between the null of martingale difference process and the alternative of a linear model with Taylor rule fundamentals. The models are estimated using data from January 1993 through January 2009.

In table 4, we examine the sensitivity of interest rate, PPP and output gap fundamental models for the same forecasting period. We conclude that these three models neither have superior forecasting ability in relation to the benchmark model nor create statistically significant results. Nevertheless, these models appear to have slightly improved relative RMSFE compared to the similar ones from the first out-of-sample period.

	Relative RMSFE	DMW-statistic	P-value
Interest rate	1.024148	0.61804	0.5519
PPP	1.022333	0.73932	0.4785
Output gap	1.055536	0.98377	0.3509

Table 4: This table includes the traditional models' performance after the end of the Swedish recession. It reports RMSFE, DMW-statistic and p-value for DMW test, between the null of martingale difference process and the alternative of a linear model with Taylor rule fundamentals. The models are estimated using data from January 1993 through January 2009.

5.4 Summary

This thesis is considerably influenced by the paper of Molodtsova and Papell (2009), who mainly examine out-of-sample predictability based on Taylor rule fundamentals. They form an equation by subtracting the Taylor rule of the foreign country from the one of the domestic country. In the left-hand-side, by using UIRP, the change in the nominal exchange rate emerges, while in the right-hand-side, there are various specifications. They also include some other models based on economic fundamentals, such as PPP fundamentals. Regarding Taylor rule fundamentals, they note strong evidence of predictability on 11 out of 12 countries, in relation with the USD. For the rest models, predictability decreases. The strongest results are reported in a symmetric Taylor rule model with heterogeneous coefficients, smoothing, and a constant.

Our analysis incorporates most of the models examined by Molodtsova and Papell(2009), using the SEK/USD exchange rate during the financial crisis. We consider two out-of-sample periods: in the beginning of the financial crisis and after the end of the crisis in Sweden. In respect of the first period, no model creates better forecasts than the random walk. In the second period, positive results occur for the Taylor rule specifications with heterogeneous coefficients. More specifically, the best performing model appears to be an asymmetric Taylor rule with heterogeneous coefficients, constant and no smoothing. According to DMW test, these results are not statistically significant. Nevertheless, Molodtsova and Papell (2009) find with the same exchange rate, that their best performing model, which is statistically significant at the 1% significance level using the the Clark and West (2006, 2007) test (hereafter "CW"), accords with our analysis model. We need to emphasize that this might just be a coincidence since the two studies are conducted on different time periods.

It is clear that the forecasting performance of all models enhances after the end of recession in Sweden. During the crisis, the Swedish interest rate hit the zero lower bound and Taylor rule played a prescriptive rather than a descriptive role (Molodtsova Papell, 2012). After 2009, there was a rebound in Swedish interest rate which may explain the results' improvement. However, the results in second period are statistically insignificant, using the DMW test. It is important to mention that in the first sample which includes the crisis, a symmetric Taylor rule with homogeneous coefficients, no constant and no smoothing rejects the null hypothesis at the 5% significant level. In addition, another three specifications with homogeneous coefficients accept the alternative hypothesis at the 10% significance level. This means, that these models create forecasts with different accuracy compared to the benchmark model. Data transformations and forecast evaluation methods are two crucial factors which affect predictive ability significantly (Rossi, 2013) and may restrict our results' significance.

Regarding the former, lack of access into real-time data negatively impacts our results. Our GDP and inflation rate variables are revised data which means that probably were not available to market participants at the examined period. Namely, their initial estimates have been updated with more information by the statistical agency. In consequence, the central banks did not know these revised values when they set the nominal interest rate (Molodtsova and Papell, 2009). This degrades the forecasting performance of the models, especially in our case with a short-horizon forecast. Most of the data has been ex ante seasonally adjusted which means it may include information that was not available during the forecast period due to specific seasonal adjustment filters applied. Also, the use of HP-filter in order to construct the output gap diverges from real-time data, since the process contains the whole sample.

We choose the DMW test in order to assess the forecasting performance of the models. Most of our results appear to be insignificant, even for a relative RMSFE below one. DMW test focuses mainly on the forecasting ability of models, since it compares the MSFE between the structural and the benchmark model. It is quite usual that the forecasting ability of a linear model is worse than the random walk's whereas there is evidence of predictability undetected by the DMW test. Thus, an issue arises due to not normal distribution of the DMW test under the null hypothesis (Rogoff and Stavrakeva, 2008). This test is undersized and hardly accepts the alternative hypothesis since random walk and all fundamental-based models are nested (Molodtsova and Papell, 2009). In other words, given that the models are nested, we anticipate higher MSFE for the structural model compared to random walk's MSFE, since the former includes more parameters for estimation which may add noise[6] into the forecasts.

The CW test corrects that estimation error and is not a minimum MSFE test[7] (Stavrakeva and Rogoff, 2009). While the majority of exchange rate literature uses the DMW test, many recent studies[8] avoid this forecast evaluation method and focus on the CW test for out-of-sample predictability in a rolling framework. A significant CW statistic indicates that there could be a forecasts' combination of the benchmark model and the structural model, whose MSFE would be lower than this of the random walk. Rossi (2013) notes that the CW test is more suitable for predictability and evaluating models "in population", given that it considers that the fundamental-based models are larger than the random walk. In our case, since we are interested in testing for forecasting ability we apply the DMW test. A highly recommended alternative for this kind of test, is the bootstrapped DMW test which has the appropriate size and also supposes that the distribution is not specific (Rogoff and Stavrakeva, 2009).

[6]Estimation of parameters that do not improve forecasting.

[7]Tests based on minimum MSFE, such as the DMW test, suggest that forecast accuracy is strictly linked to lower MSFE.

[8]The studies of Molodtsova and Papell (2009), Molodtsova and Papell (2012), Molodtsova et al. (2008), Molodtsova et al. (2011), Molodtsova and Ince (2008), GLORIA (2010).

6. Conclusion

This paper mainly focuses on the forecasting ability of the Taylor rule fundamentals for the SEK/USD exchange rate during the financial crisis. We have also included some other traditional models in order to examine if their results relate to those of the Taylor rule fundamentals. The forecasting performance of all models, which are in total 19, is compared to the random walk for two different periods. In the former out-of-sample period, which starts at the beginning of the financial crisis, almost all models create neither better nor statistically significant forecasts than the random walk. Only a symmetric Taylor rule with homogeneous coefficients, no constant and no smoothing accepts the alternative hypothesis of the DMW test. Hence, this may emphasize the volatility during the crisis in both countries and the fact that the Taylor rule may not have been followed consistently.

In the latter out-of-sample period, which starts after the end of the Swedish recession, an asymmetric Taylor rule model with heterogeneous coefficients, constant and no smoothing has the best performance. In accordance with the DMW test, this model's performance is not statistically significant. However, we find our results promising, considering that the DMW test is a very strict test which hardly accepts the alternative hypothesis when the models are nested. It would be interesting to examine if our results alter with different forecast evaluation methods, such as the bootstrapped DMW test. Also, using real-time data would probably enhance the forecasting performance of these models considerably and would be closer to the policymakers during the analysis period. This research lastly encourages scholars to evaluate the forecasting performance of the models with other currencies compared to the Swedish Krona.

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