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Testing the Properties of Financial Analysts' Predictions of Future Spot Exchange Rates (Example of CZK/EUR)

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Abstract

Exchange rate expectations play a key role in several theoretical concepts of international economics. Unfortunately, direct testing of the empirical validity was limited as information about expected future exchange rates was not available and was often replaced by future spot exchange rates or forward rates. This paper used direct exchange rate expectations as a result of a regular survey conducted by the Czech National Bank for the CZK/EUR currency pair on a one-month and one-year horizon. Using econometric tools testing the rational expectations hypothesis and alternative forms of extrapolative and adaptive expectations for the two time periods of 5/1999-12/2007 and 1/2008-12/2019, a conclusion can be drawn that the periods are statistically different. Regarding the formation of expectations, the rational expectations approach was not approved. Nevertheless, properties of extrapolative and adaptive expectations for certain periods and horizons were detected.

1. Introduction

Exchange rate expectations are a crucial aspect of financial relationships and forward-looking macroeconomic models. They are a key variable in the equation of uncovered interest rate parity that central banks use in their inflation targeting models. The previous method was based on unsustainable theoretical assumptions that approximated exchange rate expectations via the forward exchange rate or actual future spot exchange rate. But the relatively new databases that offer details of analysts' forecasts of inflation, interest rates and currency exchange rates open up a new realm of possibilities in the analysis of how market agents form their expectations. Thus, instead of using future spot exchange rates or forward rates as proxies for exchange rate expectations, we will use directly market expectations. They are available via several databases that can be found, for example, at central banks, survey firms like Consensus Economics or information agencies, Thomson Reuters and Bloomberg among others. For the purposes of this discussion, we look at information from the CNB database based on the monitoring of inflationary

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expectations of financial market agents. CNB monitoring includes analysts' forecasts for the development of the CZK/EUR spot exchange rate (CZK/EUR rate) on a monthly and annual forecast horizon (monthly frequency of observations beginning in May 1995).

The studied time series of the CZK/EUR rate for the period of 5/1999–12/2019 is visually (see Figure 1) broken down into two periods: a) the period of the Czech koruna's convergence through an exchange rate channel (5/1999–12/2007) and b) the period without an exchange rate convergence trend (1/2008–12/2019). We have formulated the hypothesis that financial analysts' predictions could have different properties in these two partial observed periods. We ask the cardinal question of whether analysts' monthly and annual forecasts for CZK/EUR rate are consistent with the rational expectations hypothesis. Alternative older hypotheses about extrapolative and adaptive expectations will also be tested, followed by a behavioural explanation of the obtained empirical evidence.

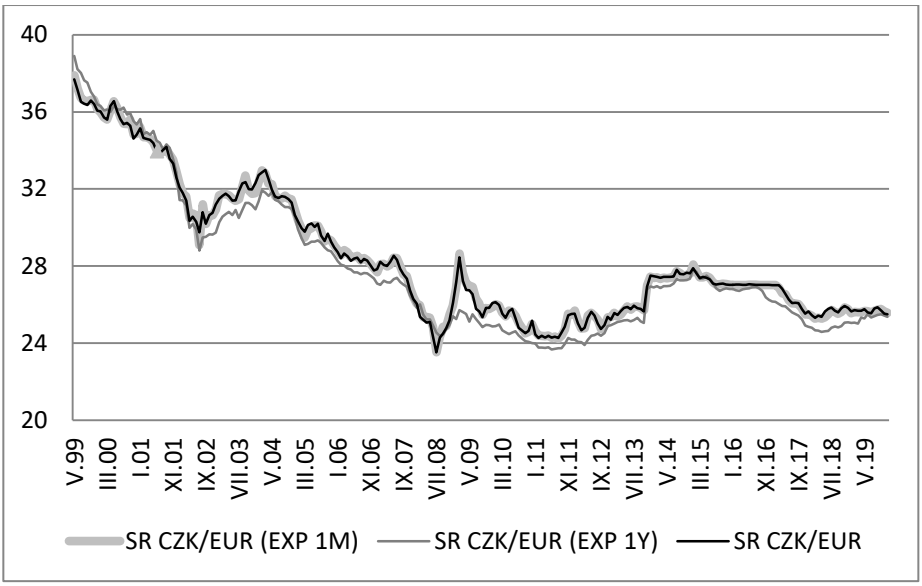
In the second section, using the unit root tests (with trend, constant and trend break) a different development of the CZK/EUR rate and exchange rate forecasts before 2008 and in the next period will be demonstrated. In the third section, we present an overview of results from current research with the objective of analysing properties of analysts' exchange rate forecasts. The fourth section summarises the basic methodological framework and approach to testing rational expectations, adaptive and extrapolative expectations. Sections five and six contain our statistical and econometric analysis of the tested hypotheses, which also includes descriptive statistics and testing of the studied time series' stationarity. We will continually carry out tests of the unbiased estimation hypotheses, non-existence of the serial correlation (relationship) of prediction errors and weak forms of market efficiency. Subsequently, we will test alternative hypotheses of expectations, i.e. the hypothesis of extrapolative and adaptive expectations. The seventh section summarises our findings.

2. Development of the CZK/EUR Spot Exchange Rate and Analysts' Forecasts in the Period of 5/1999-12/2019

We have based our empirical analysis on a time series with a monthly frequency over the period of 5/1999–12/2019 from the CNB database. [2] This includes the CZK/EUR rate (SR_t) and predicted CZK/EUR rate for one month and one year by financial analysts ($SR_t^{e(t+1)}$ or $SR_t^{e(t+12)}$, respectively). The studied time series for the CZK/EUR rate over the period of 5/1999–12/2019 is visually (see Figure 1) broken down into two periods: a) the period of the Czech koruna's convergence through an exchange rate channel (5/1999–12/2007) and b) the period without an exchange rate convergence trend (1/2008–12/2019).

[2] For the needs of the monetary policy regime of inflation targeting since May 1999, the CNB has monitored financial market inflation expectations (on a monthly basis) among analysts of domestic and foreign banks and brokerage firms that demonstrate high activity on the Czech koruna money and capital market. The set of forecasts also includes predictions of the development of the CZK/ EUR exchange rate in the monthly and annual horizons.

Figure 1 CZK/EUR Spot Exchange Rate, Monthly and Annual Forecasts of the CZK/EUR Spot Exchange Rate (5/1999–12/2019)



Source: CNB ARAD 2020

Unit root tests performed using the ADF test (Augmented Dickey-Fuller Test), ADF test with trend break and NP test (Ng and Perron Test)[3] confirm the different development in time series of the CZK/EUR rate over the periods of 5/1999–12/2007 and 1/2008–12/2019.

If the entire observed period of 5/1999–12/2019 is analysed (Table 1) in line with our hypothesis, the performed unit root tests (ADF test with trend, constant and trend break) do not reject the existence of a unit root. The trend break in 12/2007 is statistically significant at the 1% level for the actual development of the CZK/EUR rate and monthly forecasts of analysts and at a 10% significance level for analysts' annual predictions.

In the first period, 5/1999–12/2007, the hypothesis of the existence of a unit root is not rejected in any studied time series. In the second period, 1/2008–12/2019, based on the model with a constant, a unit root's existence is rejected for two time series: the actual development of the CZK/EUR rate and analysts' monthly forecasts. The nature of the time series of analysts' annual predictions is surprisingly different when the hypothesis of the existence of a unit root is not rejected for the period of 1/2008–12/2019.

These elementary findings on the nature of the studied time series lead us to draw a conclusion about the suitability of separate investigations of the nature of financial analysts' prediction formation in two observed partial periods: the exchange rate convergence trend (5/1999–12/2007) and the lack of exchange rate convergence trend (1/2008–12/2019).

[3] The algorithm for testing the models by trend and constant was chosen according to Enders (2014).

Table 1 Unit Root Tests: Augmented Dickey-Fuller Test (ADF), Augmented Dickey-Fuller Test with Trend Break (ADFTB) and Ng and Perron Test (NP)

Time series	*5/1999–12/2019*	*5/1999–12/2007*	*1/2008–12/2019*
Spot exchange rate CZK/EUR	**Not rejected** ADFTB (const., trend) does not reject Trend break 12/2007 *	**Not rejected** ADF does not reject NP does not reject	**Rejected** ADF (const.) *** NP (const.) **
Predicted spot exchange rate CZK/EUR (1 month)	**Not rejected** ADFTB (const., trend) does not reject Trend break 12/2007 *	**Not rejected** ADF does not reject NP does not reject	**Rejected** ADF (const.) *** NP (const.) ***
Predicted spot exchange rate CZK/EUR (1 year)	**Not rejected** ADFTB (const., trend) does not reject Trend break 12/2007 ***	**Not rejected** ADF does not reject NP does not reject	**Not rejected** ADF does not reject NP does not reject

Notes: *, **, *** the test rejects the existence of a unit root at a 1%, 5% and 10% significance level and it does not reject the existence of trend break at a 1%, 5% and 10% significance level, respectively.

3. An Overview of Current Research

Exchange rate expectations (or predictions) of financial analysts can be important information for central banks not only when conducting foreign exchange interventions in alternative exchange rate systems (eg Miyajima, 2013), but also for the correct setting of monetary policy instruments, especially interest rates in pursuing the central bank's main objective. In current inflation-targeting models based on the Svensson's approach or the Dynamic Stochastic General Equilibrium (DSGE) models, central banks tend to work with uncovered interest rate parity, which also includes the expected spot exchange rate. The importance of exchange rate expectations for monetary policy was first systematically analyzed by Dornbusch (1976), in the context of the dynamic IS-LM-BP model. Exchange rate expectations also play an important role in the model analysis Beneš, Hurník, Vávra (2008), who develop Svensson's approach. It solves the problem of excessive "jumps" of the spot exchange rate in the forward-looking model of uncovered interest rate parity, which are in conflict with the observed fact. Adolfson, Laséen, Lindé and Villanni (2008) examine the consequences of the modification of the uncovered interest rate parity, considering the negative correlation between the risk premium and the expected spot exchange rate, on the resulting dynamics of individual variables.

Since the second half of the 1970s, economic research has been confronted with the problem of market expectations in the area of exchange rates in connection with testing the validity of uncovered interest rate parity. However, most articles published on this topic do not consider the expectations (or forecasts) of future spot rates, as these time series were not available at the time. For testing uncovered interest rate parity, expectations of spot exchange rates were most often replaced by the forward rate as a proxy variable, e.g. McCallum (1994), Alper, Ardic and Fendoglu (2009), Lothian and Wu (2011), Chinn and Quayyum (2012), Pošta (2012), Kukal and Van Tran (2014) and Vasilyev, Busygin and Busygin (2018). But therein

arises the problem of correctly identifying and distinguishing relationships in covered interest rate parity and uncovered interest rate parity.[4]

Currently, the databases of central banks and specialised (information) agencies provide the time series of exchange rate forecasts of both financial analysts and central banks. These time series and their analysis allow us to create a more specific idea of the formation of market agents' expectations.

In her pioneering paper, Dominguez (1986) tested the unbiased estimation hypothesis using the time series for the currency pairs GBP/USD, DEM/USD, CHF/USD and JPY/USD that also involved the forecasts of 30 financial market analysts (specialists in exchange rate forecasts) for a period of one and two weeks, one and three months, respectively. For the 1983–1985 period, the author drew a conclusion about the limited rationality of market agents in view of the prediction of future spot exchange rates.

Using the panel data analysis, Chinn and Frankel (1991) analysed predictions of financial analysts (from the banking sector and supranational companies) concerning the U.S. exchange rate against 25 currencies for the period of 1988–1991 (monthly prediction frequency of one, three, six and 12 months), and they arrived at the conclusion that expectations were biased. Suk-Joong (1997) analysed financial analysts' forecasts (data source: Australian Financial Review) for short-term and long-term interest rates and the AUD/USD exchange rate (short-term forecasts for one, two, three and four weeks) for the 1984–1993 period. Based on the test of orthogonality of residuals, the possibility of the existence of so-called weak rationality was not excluded for the EUR/USD exchange rate, but the possibility of strong rationality was rejected based on the test of unbiased estimation.

Naszodi (2011) analysed the success of market analysts' forecasts from the Consensus Economics database over the period of 2003–2009. The analysis included five currency pairs (CZK/EUR, HUF/EUR, SKK/EUR, PLN/EUR and ROL/EUR) and predictions for three months, one year and two years. She drew the conclusion that analysts' forecasts for some horizons were more effective than the naive forecasting model based on the latest value.

Novotný and Raková (2011) were convinced that consensus forecasts for the USD/EUR currency pair and for the 2002–2009 period (forecasts for three months, one year and two years) were better than naive forecasts (based on the latest exchange rate values) and forecasts based on forward exchange rates (with the exception of a forward rate with two-year maturity).

Baghestani and Danila (2014) analysed the CNB database where monthly and annual forecasts of financial analysts for the CZK/EUR currency pair are available. They concluded that for the period of 2005–2012 the monthly predictions of foreign analysts, annual forecasts of domestic analysts and annual predictions of all analysts were systematically unbiased; they beat the random walk hypothesis and predicted the future direction of movement with sufficient accuracy. They also stated that domestic analysts' forecasts were efficient unlike those of foreign analysts. However, the authors did not have an opportunity (due to the date of publication) to identify the

[4] Another frequently used "solution" to this problem is to use the actual future spot exchange rate as a proxy variable for the expected spot exchange rate (e.g. Kočenda and Poghosyan, 2010; Arlt and Mandel, 2018, and Ismailov and Rossi, 2018).

different nature of CZK/EUR rate development before and after 2008 and subsequently examine whether monthly and annual predictions had different properties in the appreciation phase and in the phase of trendless development of the exchange rate.

Ince and Molodtsova (2017) used the FX4Casts database and conducted tests of unbiased estimation and orthogonality. They concluded that over the period of 2004-2012 financial analysts' predictions were strongly biased for the exchange rates of developing countries in all observed periods (three, 12 and 24 months). For the exchange rates of advanced countries, financial analysts' predictions were strongly biased for three-month forecasts and less biased for annual predictions. The exchange rates of the Czech koruna were not included in the analysis.

Beckmann and Czudaj (2020) analyze the role of expectations regarding macroeconomic fundamentals for expected exchange rate changes. They consider and test the effect of four explanatory variables - expectations of GDP growth, inflation, interest rates and current accounts (31 countries, for the period 2002 to 2017). Their analysis relies on data set provided by FX4casts (exchange rate expectations over horizons 3, 6 and 12 months). From our point of view, two conclusions of their analysis are important: a) the Czech Republic (CZK/USD exchange rate) is one of the countries for which the expected exchange rate changes cannot be explained on the basis of expected changes in fundamental factors; b) the relationships between the observed variables are not the same in the period before and after the global financial crisis.

4. Basic Methodological Approach to Testing the Rational Expectations Hypothesis on an Example of Financial Analysts' Predictions

According to the rational expectations hypothesis (Muth, 1961), expectations are fully rational if available information has been used in an optimal way. There is no other unbiased prediction model that would have a smaller variance of the actually achieved (i.e. backward) prediction errors. The actually achieved prediction errors are random with the mean of zero and are caused by random events (shocks) or unsystematic individual errors of single agents in their predictions.[5] In the context of the rational expectations hypothesis, Fama (1965 and 1970) formulated hypotheses about the weak, semi-strong and strong forms of market efficiency. Although his articles are aimed at stock market analysis, his fundamental ideas have general analytical validity. Testing the weak form of efficiency, i.e. that any information about past exchange rate developments has been completely integrated into new forecasts for exchange rates, can be understood as testing the necessary condition for the validity of the rational expectations hypothesis. Pesaran (1987) formulated four econometrically testable conditions for the validity of the rational expectations hypothesis. Firstly, it tests the hypothesis of unbiased estimation. Secondly, it tests the properties of forecasting errors that should be orthogonal to the agents' information available at the time of prediction formulation. Thirdly, it tests the

[5] The requirement for an unsystematic forecasting error in view of the theory is met also when there exists a systematic error of agents typically at a given time that is, however, at random.

condition of serial uncorrelatedness of prediction errors.[6] Fourthly, it is the test of prediction efficiency, i.e. forecasting error is not related to predicted variables from preceding periods.

Based on these methodological fundamentals, the properties of financial analysts' monthly and annual forecasts about the development of the CZK/EUR rate will be tested. In the framework of descriptive statistics, the analysis will look at a) whether predicted change in the spot exchange rate has the same mean value (and standard deviation) as actual change in the spot exchange rate, b) whether annual predictions of changes in the spot exchange rate are consistent with monthly forecasts of changes in the spot exchange rate.[7]

In an econometric analysis, three scopes of problems will be addressed: a) the validity of the unbiased estimation hypothesis for monthly and annual predictions of the spot exchange rate, b) the independence of forecasting errors of the spot exchange rate with respect to information known at the time of prediction realisation (specifically the information about past changes in the exchange rate and preceding errors in predictions) and c) the validity of hypotheses about alternative models of expectations, i.e. extrapolative expectations hypothesis and adaptive expectations hypothesis formulated by Metzler (1941) and Nerlove (1958).

5. Tested Time Series and Their Descriptive Statistics

Based on the time series 5/1999–12/2019 (monthly frequency) of the CZK/EUR rate (SR_t), the predicted CZK/EUR rate for one month and for one year on the part of financial analysts ($SR_t^{e(t+1)}$ or $SR_t^{e(t+12)}$, respectively), we define monthly and annual change in the exchange rate ($SR_t - SR_{t-1}$, and $SR_t - SR_{t-12}$) and predict monthly and annual change in the exchange rate ($SR_{t-1}^{e(t)} - SR_{t-1}$ and $SR_{t-12}^{e(t)} - SR_{t-12}$) along with the error of monthly and annual forecasts ($SR_t - SR_{t-1}^{e(t)}$ and $SR_t - SR_{t-12}^{e(t)}$), which will underscore our econometric analysis.

Significant differences in both observed periods that were already identified in the initial level data in Chapter 2 are confirmed by descriptive statistics (Table 2). While in the period of 5/1999–12/2007 (i.e. before the economic and financial crisis) the mean value of month-on-month changes was −0.1106 CZK/EUR; in the subsequent period of 1/2008–12/2019, the exchange rate did not show a clear appreciation trend and the mean value of value of month-on-month changes was close to zero (−0.0056 CZK/EUR).

[6] At the same time, the possibility of the serial correlation of forecasting errors in the moving average process is formulated if the prediction frequency is not consistent (it is more frequent) with the time horizon of forecasts.

[7] The consistency of monthly and annual predictions of changes in the spot exchange rate will be assessed with regard to their mean values that indicate average depreciation and appreciation expectations for the studied period.

Table 2 Descriptive Statistics of the Tested Time Series

		Monthly change in exchange rate $SR_t - SR_{t-1}$	Forecast of monthly change in exchange rate $SR^{e(t)}_{t-1} - SR_{t-1}$	Error of monthly forecast $SR_t - SR^{e(t)}_{t-1}$	Annual change in exchange rate $SR_t - SR_{t-12}$	Forecast of annual change in exchange rate $SR^{e(t)}_{t-12} - SR_{t-12}$	Error of annual forecast $SR_t - SR^{e(t)}_{t-12}$
Mean	*a*	−0.0494	0.0236	−0.0730	−0.5456	−0.4717	−0.0739
	b	−0.1106	0.0305	−0.1411	−1.1280	−0.2842	−0.8438
	c	−0.0056	0.0186	−0.0242	−0.1735	−0.5915	0.4180
Median	*a*	−0.0410	0.0060	−0.0440	−0.4840	−0.5225	0.0625
	b	−0.1420	0.0580	−0.1650	−1.2370	−0.4170	−1.0505
	c	−0.0135	−0.0095	−0.0020	−0.0715	−0.5790	0.4230
Maximum	*a*	1.2900	0.6040	1.6960	3.0830	1.4990	3.0770
	b	1.0470	0.4140	1.6960	2.1610	1.4990	3.0770
	c	1.2900	0.6040	1.5990	3.0830	1.0310	2.5870
Minimum	*a*	−1.2300	-0.6490	−1.4110	−4.8010	−2.7490	−4.6410
	b	−1.0320	−0.6490	−1.2640	−4.1940	−1.4920	−4.6410
	c	−1.2300	−0.3090	−1.4110	−4.8010	−2.7490	−3.8610
Std. Dev.	*a*	0.3437	0.1650	0.4325	1.43230	0.5846	1.5840
	b	0.3447	0.1838	0.4634	1.4063	0.6891	1.8073
	c	0.3374	0.1505	0.4036	1.3248	0.4716	1.1914
Observations	*a*	247	247	247	236	236	236
	b	103	103	103	92	92	92
	c	144	144	144	144	144	144

Notes: a) period 5/1999–12/2019 (resp. 5/2000–12/2019), b) period 5/1999–12/2007 (resp. 5/2000–12/2007) and c) period 1/2008–12/2019.

5.1 Properties of Monthly Forecasts of the CZK/EUR Spot Exchange Rate

Table 2 documents different characteristics of the time series as concerns actual monthly changes in the exchange rate and predicted monthly changes in the exchange rate on the part of financial analysts. While predicted monthly changes in the spot exchange rate have the positive mean value in both observed partial periods, the mean values of actual changes in the spot exchange rate are negative, particularly in the period of 5/1999–12/2007.[8]

Standard deviation in monthly forecasts of changes in the spot exchange rate is smaller in comparison with actual monthly changes in the spot exchange rate in both observed partial periods.[9] The mean value of the monthly forecasting error is different from zero mainly in the first period of 5/1999–12/2007, when in monthly predictions financial analysts systematically underestimated the appreciation convergence trend of the Czech koruna.

All the above-observed facts indicate the possibility of a systematic error in financial analysts' monthly predictions of the development of the CZK/EUR rate.

[8] Pearson's χ^2 test (goodness of fit test) at a 5% significance level rejects the hypothesis about the fit of the mean values of the observed time series in both partial periods.

[9] Analysts do not usually tend to predict any great changes in exchange rates because there is a risk of high error in prediction. As is shown below in the text, they attach great importance to the model of extrapolative and adaptive expectations. At the same time, they prefer to place predictions near the consensus even though a consensual prediction is often wrong. An individual analyst will not be evaluated negatively for an erroneous forecast so long as all analysts have been equally mistaken.

5.2 Properties of Annual Forecasts for the CZK/EUR Spot Exchange Rate

For the entire observed period of 5/2000–12/2019, the mean values of predicted and actual annual changes in the CZK/EUR rate have identical negative signs, and Pearson's χ^2 test (goodness of fit test) at a 5% significance level does not reject the fit of the means. The mean value of the error of annual predictions for the spot exchange rate in the whole observed period is close to zero.

The evaluation of the results of descriptive statistics for the two observed partial periods suggests that while in the appreciation convergence period of 5/2000–12/2007 analysts predicted on average a smaller appreciation change in the spot exchange rate compared to subsequent reality, in the "trendless" period of 1/2008–12/2019 their forecasts on average overestimated the strengthening of the Czech koruna compared to the subsequent reality.[10] Pearson's χ^2 test (goodness of fit test) rejects the hypothesis about the fit of mean values at a 5% significance level in both observed partial periods. A difference between both observed partial periods is also demonstrated by different signs in the mean value of the annual forecasting error. In the first period, the analysts tended to underestimate the appreciation trend of the Czech koruna. On the contrary, in the second period they tended to overestimate the appreciation trend of the Czech koruna.

It is worth noting that while the mean value of monthly forecasts of changes in the exchange rate is positive (i.e. depreciation), the mean value of annual predictions for exchange rate changes is negative (i.e. appreciation). This fact indicates some inconsistency in short-term and medium-term prediction models of financial analysts.

5.3 Testing the Stationarity of Defined Time Series

Tests of the stationarity of time series (unit root hypothesis) were performed by the Augmented Dickey-Fuller (ADF) test and the Ng and Perron (NP) test.

While the hypothesis of the unit root existence is rejected in all cases for monthly changes in the exchange rate and predictions of monthly changes in the exchange rate (Table 3), for annual changes and forecasts of annual changes (Table 4) the results are ambiguous in some cases.

Table 3 Unit Root Test of Monthly Forecasts: Augmented Dickey-Fuller (ADF) Test and Ng and Perron (NP) Test

Time series	*5/1999–12/2019*	*5/1999–12/2007*	*1/2008–12/2019*
Monthly change in exchange rate	**Rejected** ADF (const.) * NP (const.) **	**Rejected** ADF (const.) * NP (const.) **	**Rejected** ADF (const.) * NP (const.) *
Prediction of monthly change in exchange rate	**Rejected** ADF (const.) * NP (const.) **	**Rejected** ADF (const.) * NP (const.) *	**Rejected** ADF (const.) * NP (const.) *
Error in monthly prediction	**Rejected** ADF (const.) * NP (const.) *	**Rejected** ADF (const.) * NP (const.) *	**Rejected** ADF (const.) * NP (const.) *

Notes: *, **, *** the test rejects the unit root existence at a 1%, 5% and 10% significance level.

[10] This reality can be explained by a generally prevailing opinion about the convergence process continuation through an exchange rate channel that was embodied also in macroeconomic forecasting models of official institutions.

Table 4 Unit Root Test of Annual Forecasts: Augmented Dickey-Fuller (ADF) Test and Ng and Perron (NP) Test

Time series	*5/2000–12/2019*	*5/2000–12/2007*	*1/2008–12/2019*
Annual change in exchange rate	**Rejected** ADF ** NP (const.) *	**Ambiguous** ADF does not reject NP (const. and trend) ***	**Ambiguous** ADF ** NP does not reject
Prediction of annual change in exchange rate	**Rejected** ADF (const.) * NP (const. and trend) ***	**Rejected** ADF (const.) * NP (const. and trend) ***	**Rejected** ADF (const.) * NP (const.) *
Error in annual prediction	**Rejected** ADF * NP (const. and trend) ***	**Ambiguous** ADF does not reject NP (const. and trend) **	**Rejected** ADF * NP (const.) ***

Notes: *, **, *** the test rejects the unit root existence at a 1%, 5% and 10% significance level.

6. Econometric Analysis of Rational, Extrapolative and Adaptive Expectations

Using the econometric analysis, the properties of monthly and annual predictions of financial analysts will be tested.[11] Indirect testing of the rational expectations hypothesis will be done by means of testing the unbiased estimation hypothesis, the non-existence of serial correlation in forecasting errors, and the weak efficient market hypothesis. Subsequently, "older" competing hypotheses of extrapolative and adaptive expectations will be tested. Estimations were done by the least-squares method. The autocorrelation in the model was verified by the Ljung Box Q test and a correlogram of residuals. With regard to the nature of the foreign exchange market, which is affected by speculative attacks (potentially by unexpected interventions of central banks) in some periods, the residuals of estimated models usually suffer from heteroscedasticity. To solve the problem of estimation efficiency and a possibility distortion of the calculation of confidence intervals in the respective estimated parameters, the procedure for solving the problem of heteroscedasticity and autocorrelation was used (HAC, Newey and West, 1987).

6.1 Test of the Unbiased Estimation Hypothesis

According to the unbiased estimation hypothesis, market expectations (financial analysts' forecasts in our study) are an unbiased predictor of future spot exchange rates. Considering the problems of the stationarity of time series at a level, this hypothesis is usually tested using the relationship for actual and expected changes in the exchange rate:

$$SR_t - SR_{t-n} = \gamma_0 + \gamma_1 (SR_{t-n}^{e(t)} - SR_{t-n}) + \tau_t \,,$$

where τ_t is white noise and n is the number of months. Null hypotheses about the parameters: $\gamma_0 = 0$ and $\gamma_1 = 1$.

[11] The econometric software EViews 11 was used for testing.

Table 5 Test of Unbiased Estimation (Explained Variable: Actual Change in the Exchange Rate $SR_t - SR_{t-1}$ and $SR_t - SR_{t-12}$)

	Constant	*Predicted change in exchange rate* $SR^{e(t)}_{t-1} - SR_{t-1}$ $SR^{e(t)}_{t-12} - SR_{t-12}$	*D-W stat.*	*Autocorrelation of higher-order residuals*	*R sq. F test*
6/1999–12/2007 (monthly forecasts)	−0.0826** (−2.5013)	−0.9184* (−9.4410)	1.8847	None	0.2399 31.8800*
1/2008–12/2019 (monthly forecasts)	0.0053 (0.1715)	−0.5807* (−6.7465)	1.5919	None	0.0672 10.2241*
6/2000–12/2007 (annual forecasts)	−0.7665** (−2.4578)	0.1633* (−10.631)	1.6857	AR(1) 0.9541* (18.1418) MA(12) 0.8900* (-29.2310)	0.9393 448.440*
1/2008–12/2019 (annual forecasts)	0.5071 (1.0055)	0.9717 (-0.1900)	1.9711	AR(1) 0.9117* (18.6400) MA(1) -0.3502* (3.2667)	0.9263 586.897*

Notes: The values of estimated parameters are shown in the first row; in the second row, t-statistics are in brackets. *, **, *** denote statistically significant parameters at a 1%, 5% and 10% significance level.

In monthly forecasts of changes in the CZK/EUR rate (Table 5), surprisingly, estimated parameters have a negative sign and they are different from one at a 1% significance level. The interpretation is that in both observed periods the actual monthly changes in the CZK/EUR rate developed on average in the opposite direction to what was indicated by financial analysts' monthly predictions. Greater errors in monthly forecasts occurred in the period of the Czech koruna's convergence trend (6/1999–12/2007).

In annual predictions of changes in the CZK/EUR rate (Table 5) the parameters show positive signs. In the first period of 6/2000–12/2007, the constant is different from zero at a 5% significance level (as in monthly forecasts). The negative sign indicates analysts did not expect part of the Czech koruna appreciation trend. In the second period of 1/2008–12/2019, the parameter is not statistically significantly different from one in line with the unbiased estimation hypothesis. However, in both periods the estimations show the statistically significant autocorrelation of first-order residuals, which is not consistent with the unbiased estimation hypothesis. This empirical evidence can be explained by some persistence of financial analysts' forecasting errors that stems from the fact that new information influencing annual predictions of the exchange rate often has slower (lower) frequency than one month.[12] The statistically significant process MA(12) and MA(1) in annual predictions is in line with the evidence of Pesaran (1987) and Suk-Joong (1997) and

[12] This is mainly statistical information from national accounts (typically GDP and its structure) available only with a quarterly frequency, statistics of the balance of payments (monthly statistics are subject to significant revisions; monthly data on the financial account are only estimates) and the foreign investment position of the country. Exchange rate forecasts are often a part of the overall macroeconomic forecast. Macroeconomic models are typically based on quarterly data and are usually revised at quarterly intervals.

is related to the monthly frequency of observations if the prediction of the exchange rate for one year is currently used.

6.2 Test of the Non-Existence of a Serial Correlation of Forecasting Errors

The test of the non-existence of a serial correlation of forecasting errors verifies whether preceding errors in predictions have been fully considered in new forecasts. In backward observations and testing, forecasting errors should not be constant and should not depend on their preceding values:

$$SR_t - SR_{t-1}^{e(t)} = \beta_0 + \sum_{n=1}^{\infty} \beta_{t-n}(SR_{t-n} - SR_{t-n-1}^{e(t-n)}) + \omega_t \ ,$$

where ω_t is white noise. Null hypotheses about the parameters: $\beta_0 = 0$ and $\beta_{t\text{-}n} = 0$.

Table 6 Test of the Serial Correlation (Explained Variable: Forecasting Error in $SR_t - SR^{e(t)}_{t-1}$ and $SR_t - SR^{e(t)}_{t-12}$)

	Constant	*Lagged forecasting error in* $SR_{t-1} - SR^{e(t-1)}_{t-2}$ $SR_{t-1} - SR^{e(t-1)}_{t-13}$	*D-W stat.*	*Autocorrelation of higher-order residuals*	*R sq.* *F test*
7/1999–12/2007 (monthly forecasts)	−0.1125** (−2.2530)	0.1660 (0.8520)	2.0275	None	0.0278 2.8605***
1/2008–12/2019 (monthly forecasts)	−0.0146 (−0.4931)	0.3570* (3.6779)	1.8966	None	0.1288 20.9932*
7/2000–12/2007 (annual forecasts)	−0.0448 (−0.5420)	0.9306* (28.7716)	1.7887	AR(3) 0.3382** (2.5003)	0.9310 573.06*
1/2008–12/2019 (annual forecasts)	0.0583 (0.8141)	0.8857* (11.4850)	1.9712	AR(1) 0.3611** (2.1973)	0.9085 700.121*

Notes: The values of estimated parameters are shown in the first row; in the second row, t-statistics are in brackets. *, **, *** denote statistically significant parameters at a 1%, 5% and 10% significance level.

Table 6 shows the one-lag estimations because tests did not confirm the existence of the serial correlation of forecasting errors at a longer lag. In the monthly predictions of changes in the CZK/EUR rate for the period of 7/1999–12/2007, a systematic error occurred in which the negative value of the statistically significant constant at a 5% significance level indicated that financial analysts repeatedly underestimated the Czech koruna's appreciation trend. The serial correlation of monthly forecasting errors was observed in the period 1/2008–12/2019. In annual predictions of changes in the CZK/EUR rate in both observed periods the estimated parameters were different from zero at a 1% statistical significance level. The specific values of the parameters were close to one, which indicated a great persistence of forecasting errors.

6.3 Test of the Weak Form of Market Efficiency

The foreign exchange market satisfies the condition of the weak form of efficiency if any information about past exchange rate developments is fully included in new predictions. In backward observations and testing, it should be applicable that

forecasting errors are not a function and they are not explainable by the previous known changes in exchange rates:[13]

$$SR_t - SR_{t-1}^{e(t)} = \alpha_0 + \sum_{n=1}^{\infty} \alpha_{t-n}(SR_{t-n} - SR_{t-n-1}) + \varepsilon_t \ ,$$

where ε_t is white noise. Null hypotheses about the parameters: $\alpha_0 = 0$ and $\alpha_{t\text{-}n} = 0$.

Table 7 Test of the Weak Form of Efficiency (Explained Variable: Forecasting Error $SR_t - SR^{e(t)}_{t-1}$ and $SR_t - SR^{e(t)}_{t-12}$)

	Constant	*Lagged change in exchange rate* $SR_{t-1}-SR_{t-2}$ $SR_{t-1}-SR_{t-13}$	*D-W stat.*	*Autocorrelation of higher-order residuals*	*R sq.* *F test*
7/1999–12/2007 (monthly forecasts)	−0.1008** (−2.146)	0.3208 (1.3802)	1.9048	None	0.0574 6.0919**
1/2008–12/2019 (monthly forecasts)	−0.0205 (−0.6509)	0.4455* (4.0311)	1.9190	None	0.1402 23.1625*
7/2000–12/2007 (annual forecasts)	−0.3041 (−0.3377)	0.2677*** (1.7127)	2.2189	AR(1) 0.9397* (24.5847)	0.9287 566.364*
1/2008–12/2019 (annual forecasts)	0.5490*** (1.8434)	0.2926* (3.0586)	1.9320	AR(1) 0.9054* (17.2692)	0.9101 713.721*

Notes: The values of estimated parameters are shown in the first row; in the second row, t-statistics are in brackets. *, **, *** denote statistically significant parameters at a 1%, 5% and 10% significance level.

Table 7 shows the one-lag estimations because tests did not confirm the statistical significance of predictions with a longer lag. In monthly forecasts of changes in the CZK/EUR rate for the period of 7/1999–12/2007, we arrive at the same conclusion about systematic error as in the preceding test of the serial correlation of forecasting errors (Table 6). In other cases, i.e. monthly predictions for the period of 1/2008–12/2019 and annual predictions for the 7/2000 the rational expectations hypothesis 12/2007 and 1/2008–12/2019 periods, based on statistically significant parameters at a 1% and 10% significance level we draw the conclusion that the one-period lagged change in the CZK/EUR rate can explain certain errors in analysts' forecasts.

6.4 Testing the Extrapolative Expectations Hypothesis

A model of extrapolative expectations was formulated by Metzler (1941) as part of the analysis of dynamics of inventories and sales development in the business cycle. If his approach to the formation of expectations is applied to the foreign exchange market and the spot exchange rate, the expectations (or forecasts) of market agents are influenced by the latest value of the spot exchange rate and its dynamics (change) from the preceding period.

[13] The so-called autocorrelation test of weak-form market efficiency (Fama, 1965) requires the uncorrelatedness of exchange rate changes. However, if observed change in the exchange rate is divided into predicted and unpredicted (i.e. prediction error), the uncorrelatedness with past changes in the exchange rate is required only for the unpredicted change. On the contrary, the predicted change can be correlated with the past change if changes in the exchange rate are persistent.

$$SR_t^{e(t+1)} = SR_t + \kappa_1(SR_t - SR_{t-1})$$

Where $\kappa_1 > 0$ indicates that market participants expect the same direction of exchange rate movement in the future, and $0 > \kappa_1 > -1$ indicates that market participants tend to correct past developments in their expectations and expect the opposite movement.

The econometric equation that is appropriate for ensuring the stationarity of the tested time series and that allows for use of the least-squares method is as follows:

$$SR_t^{e(t+1)} - SR_t = \kappa_0 + \kappa_1(SR_t - SR_{t-1}) + \nu_t \,,$$

where ν_t is white noise. Null hypotheses about the parameters: $\kappa_0 = 0$ and $\kappa_1 = 0$.

Table 8 Test of Extrapolative Expectations (Explained Variable: Predicted Change in Exchange Rate $SR^{e(t)}_{t-1} - SR_{t-1}$ and $SR^{e(t)}_{t-12} - SR_{t-12}$)

	Constant	*Latest change in exchange rate* $SR_{t-1} - SR_{t-2}$ $SR_{t-1} - SR_{t-13}$	*D-W stat.*	*Autocorrelation of higher-order residuals*	*R sq.* *F test*
6/1999–12/2007 (monthly forecasts)	0.0079 (0.34902)	−0.1952** (−2.0131)	2.1432	None	0.1349 15.7491*
1/2008–12/2019 (monthly forecasts)	0.0179 (0.8776)	−0.1550* (−3.8606)	2.1782	AR(1) 0.4918* (4.9601)	0.3811 43.409*
6/1999–12/2007 (annual forecasts)	−0.6699* (−3.1285)	−0.1813** (−2.2899)	1.9426	AR(1) 0.8686* (18.3581)	0.7657 143.823*
1/2008–12/2019 (annual forecasts)	−0.5984* (−4.4174)	−0.2976* (−3.5146)	1.8784	AR(1) 0.8594* (21.0425)	0.7577 219.244*

Notes: The values of estimated parameters are in the first row; in the second row, t-statistics are in brackets. *, **, *** denote statistically significant parameters at a 1%, 5% and 10% significance level.

In the case of monthly predictions of changes in the CZK/EUR rate (Table 8), the constants are close to zero (statistically insignificant). The estimated parameters have a negative sign and are different from zero at 5%, resp. 1% level of significance. A negative sign indicates that financial analysts, in the case of their monthly predictions of the CZK/EUR rate, tended to predict future depreciation in the previous appreciation and vice versa.

In other words, they tended to predict a market correction. In annual predictions of changes in the CZK/EUR rate, the results are similar but statistically significant constants (at a 1% significance level) with the negative sign indicate analysts tended to predict the systematic appreciation of the Czech koruna, which was probably supported by an adjustment of the exchange rate convergence trend in the core projection model of the Czech National Bank.[14]

[14] In its model apparatus, the CNB assumes the long-term continuation of a convergence story reflected in the real appreciation of the Czech koruna against the euro. With regard to a similar adjustment of inflation targets of the CNB and the ECB, the result is an assumption of long-term nominal strengthening of the

6.5 Testing the Adaptive Expectations Hypothesis

The adaptive expectations model is the most frequently considered "competing" conception in relation to the rational expectations hypothesis (Nerlove, 1958). The expected exchange rate is equal to the weighted function of the exchange rate of a current period and the exchange rate expected in the previous period:

$$SR_t^{e(t+1)} = \lambda SR_t + (1-\lambda) SR_{t-1}^{e(t)}$$

where $\lambda \in (0,1)$.

After equation rearrangements, we get the form of the notation of adaptive expectations that is usually suitable for ensuring the stationarity of the tested time series and that allows using the least-squares method:

$$SR_t^{e(t+1)} - SR_t = (\lambda - 1)(SR_t - SR_{t-1}) + (1-\lambda)(SR_{t-1}^{e(t)} - SR_{t-1})$$

The tested econometric equation:

$$SR_t^{e(t+1)} - SR_t = \varphi_0 + \varphi_1 (SR_t - SR_{t-1}) + \varphi_2 (SR_{t-1}^{e(t)} - SR_{t-1}) + \mu_t \,,$$

where μ_t is white noise. Null hypotheses about the parameters: $\varphi_0 = 0$ and $\varphi_1 = 0$, at the same time it holds good $\varphi_1 = (\lambda - 1)$ and $\varphi_2 = (1 - \lambda)$.

Table 9 Test of Adaptive Expectations (Explained Variable: Predicted Change in Exchange Rate $SR^{e(t)}_{t-1} - SR_{t-1}$ and $SR^{e(t)}_{t-12} - SR_{t-12}$)

	Const.	*Latest change in exchange rate* $SR_{t-1} - SR_{t-2}$ $SR_{t-1} - SR_{t-13}$	*Lagged expected change in exchange rate* $SR^{e(t-1)}{}_{t-2} - SR_{t-2}$ $SR^{e(t-1)}{}_{t-13} - SR_{t-13}$	*D-W stat.*	*Autocorrelation of higher-order residuals*	*R sq.* *F test*
6/1999–12/2007 (monthly forecasts)	0.0080 (0.3397)	−0.2065* (−3.0170)	−0.0433 (−0.2651)	2.0735	None	0.1363 7.8927*
1/2008–12/2019 (monthly forecasts)	0.0097 (0.8373)	−0.1463* (−3.1689)	0.4260* (4.5118)	2.0160	None	0.3616 39.929*
6/2000–12/2007 (annual forecasts)	−0.6381* (−3.1263)	−0.1943** (−2.2266)	0.1140 (1.1071)	1.9819	AR(1) 0.8619* (17.823)	0.7692 96.639*
1/2008–12/2019 (annual forecasts)	−0.3630*** (−1.8258)	−0.4474* (−4.4271)	0.3911* (3.0313)	2.0046	AR(1) 0.9115* (27.516)	0.7897 175.32*

Notes: The values of estimated parameters are shown in the first row; in the second row, t-statistics are in brackets. *, **, *** denote statistically significant parameters at a 1%, 5% and 10% significance level.

In monthly and annual forecasts of changes in the CZK/EUR rate (Table 9) in the period of 6/1999–12/2007 (or 6/2000–12/2007, respectively), the parameters of lagged expected change in the exchange rate are statistically insignificant, which is in

Czech koruna by virtue of convergence. This is modified in the models of the CNB by the condition of uncovered interest rate parity adjusted for the risk premium.

support of the extrapolative expectations model. In monthly and annual forecasts of changes in the CZK/EUR rate in the period 1/2008–12/2019, the parameters of lagged expected change in the CZK/EUR rate are positive and for the last observed change in the spot exchange rate are negative (all parameters are statistically significant at 1% significance level). The predictions of financial analysts in this period were based on two tendencies: a) partial inertia of spot exchange rate forecasts, b) expected partial correction in spot exchange rate developments.

7. Conclusion

Our goal was to analyse the nature of financial analysts' monthly and annual forecasts of the CZK/EUR spot exchange rate as viewed by different schools of expectation theories, i.e. we have forked directly with market expectations and not with conventional proxies like future spot exchange rates or forward rates. Our analysis is based on the data from CNB monitoring and covers the time period from May 1999 to the end of 2019.

The visual and statistical analysis (tests of unit root with constant, trend and trend break) lead us to the separate testing of two periods: with the convergence trend of the Czech koruna (5/1999–12/2007) and trendless development (1/2008–12/2019). In view of the descriptive statistics, financial analysts' forecasts do not meet the required properties of rational expectations. The results revealed certain different characteristics of the two analysed periods in both monthly and annual predictions. In the period of appreciation of the Czech koruna, which lasted until the beginning of the global financial crisis, financial analysts, in their predictions of annual changes in the CZK/EUR rate, on average underestimated the strengthening of the Czech koruna compared to reality. In the subsequent trendless period 1/2008–12/2019, on the other hand, their annual forecasts overestimated the strengthening of the Czech koruna on average in comparison with the actual development. Descriptive statistics signal the possibility of systematic errors even in the case of predictions of monthly changes in the CZK/EUR rate. While the actual average changes in the spot exchange rate were negative (which signifies the appreciation of the Czech koruna), the predictions of monthly changes in the spot exchange rate made by financial analysts were positive on the contrary. The difference between the mean values was statistically significant especially during the first analysed period 5/1999–12/2007.

The econometric analysis did not confirm that financial analysts' forecasts complied with the elementary tested conditions of rational expectations. Tests of the unbiased estimation condition for monthly predictions of changes in the CZK/EUR rate showed that the estimated parameters in both monitored periods have surprisingly negative signs. It can be interpreted as follows: average monthly changes in the CZK/EUR rate developed in the opposite direction to what was suggested by the monthly predictions of financial analysts. In annual forecasts of changes in the CZK/EUR rate, estimated parameters show positive signs but have the statistically significant autocorrelation structure of first-order residuals, which is not consistent with the unbiased estimation hypothesis. In the period of the appreciating convergence trend of the Czech koruna before 12/2007, financial analysts systematically underestimated the appreciation of the Czech koruna in their monthly and annual forecasts (statistically significant constants with a negative sign). Tests of

the non-existence of serial correlation of forecasting errors demonstrated that the predictions of monthly changes in the CZK/EUR rate in the period of 7/1999–12/2007 showed a systematic error (a statistically significant constant) and in the next period of 1/2008–12/2019 there was a serial correlation of monthly forecasting errors. In annual predictions of changes in the CZK/EUR rate, estimated parameters were statistically significant in both observed periods and their values were close to one, which suggested a considerable persistence of forecasting errors. The testing of the weak form of foreign exchange market efficiency proved that one-period lagged change in the CZK/EUR rate could explain certain errors in financial analysts' predictions for monthly forecasts in the period of 1/2008–12/2019 and annual predictions in both monitored periods.

When testing alternative hypotheses about the formation of expectations, we found that financial analysts' predictions had the properties of extrapolative expectations in monthly forecasts of changes in the CZK/EUR rate. It is worth noting that in both periods tested, financial analysts tended to predict the future depreciation of the Czech koruna if it had appreciated during the previous period (and vice versa). In annual forecasts of changes in the CZK/EUR rate, these are no longer "pure" extrapolative expectations.

Statistically significant constants with negative signs signal that the forecasts of financial analysts assumed a long-term appreciation trend of the Czech koruna. This is also the case in the second reviewed period (after 2007), when the Czech koruna no longer evinced any appreciating convergence trend. In monthly and annual forecasts of changes in the CZK/EUR rate, financial analysts' predictions have the character of adaptive expectations during the trendless period after 2007. The parameters for lagged expected spot exchange rate changes are statistically significant, signalling a certain persistence of the CZK/EUR rate predictions.

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