Short-Term Dependencies between the Volatility of Currency, Money and Capital Markets: The Case of Poland

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Abstract

The paper presents GARCH models for the Euro-Polish złoty and US dollar-Polish złoty currency rates. It applies the approach within which both the conditional variance function and the mean equation of the ARCH class model are expanded simultaneously. The basic regression equation incorporates causal dependencies between currency prices and the main characteristics of domestic and international currency, money and capital markets. The paper provides an insight into the currency market microstructure as the presented investigation takes into account the intradaily features of the market. Model selection and performance has been evaluated by the use of direction quality measures.

Keywords: currency market, GARCH models, direction quality measures, emerging markets

JEL Classification: G15, C51

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1. Introduction

The volatility of financial market prices can be investigated through the analysis of numerous interdependencies among different instruments, across individual market segments as well as various geographical markets. Very often the decisions of investors are motivated by the vigilant, yet in many cases intuitive, examination of the behavior of other related financial instruments. Only seldom the formalized methods of analysis, aiming at proper capturing of those relationships, are applied.

The paper presents GARCH models of the currency rates EUR/PLN and USD/PLN. The following hypotheses were verified. Firstly, the volatility of the currency market in Poland depends on the volatility of other money market instruments, such as domestic and foreign interest rates and forward rates. Secondly, it is in a short-run influenced by the dynamics of major international currencies – mainly EUR/USD rate. Thirdly, there exist dependencies among different segments of the financial market – in particular between capital market (stock market) and the currency market.

2. Short-term dependencies on financial markets

In the long run the behavior of financial markets is strongly dependent on the macroeconomic factors. In the short or ultra-short time-intervals however macro-variables do not play a significant role. This is due to the following two reasons. From the economic side, the daily or intradaily time horizon of investors is so short that the macroeconomic events do not influence the prices in such time spans
(except for the single, infrequently occurring events). From the technical point of view, there is little congruence between the frequencies of available data, so the appropriate analyses cannot be directly conducted.

Short-term dependencies on financial markets usually concern the following areas of investigation: the price-volume relationship and the interdependencies among different market segments and geographical regions.

Price-volume relationship is one of the most extensively explored causal dependencies in the field of high frequency data econometrics of financial markets. Some interesting properties of volume in relation to price volatility in financial markets have been reported. Campbell et al. (1992) as well as Morse (1978) argue that there exist a dependency between volume of trading and the serial correlation of stock returns. Lamoreux and Lastrapes (1990) prove that the introduction of volume into the conditional variance equation of an ARCH class model causes reduction of the ARCH effect. Lyons (1995) gives an insight into the FX market microstructure and finds that the low-intensity trades are more informative than when the trading intensity is high. Unfortunately, the data concerning volume of trade is not widely available for currency market and most of the research in this field is done for the stock market instruments where volume is reported on a regular basis by all the stock exchanges.

The second group of dependencies exists due to the globalization of financial markets and the increasing role of short-term (very often speculative) investors, who ignite volatility and transmit it to different markets. Most of them constantly watch the behavior of the major international currencies, such as EUR/USD, JPY/USD or JPY/EUR as it is widely believed that their volatility is directly related to the changeability of other international currency movements and the resulting price changes.
Besides that investors and traders very often pay attention to the volatility of other instruments of the domestic and international financial markets – especially money, capital as well as derivative markets. In a short-run the linkages among such instruments as major international currency rates, forward rates on those currencies, domestic and international interest rates as well as the stock exchange indices can be investigated and tested. In case of those variables most of them can be used for the econometric research at the high frequency data level because all of them are available as daily or intradaily quotations.


The development of Polish currency market can be analyzed from the perspective marked out by the macroeconomic transformation process in Poland. The beginning of the 1990s was characterized by a radically high level of the intervention of monetary authorities into the mechanisms of the money and currency markets. The main reason for that was high dynamics of the adjustment processes observed directly after lifting of the administrative restrictions characteristic of the centrally planned economy. The monetary and fiscal policy instruments have been assigned a role of the economic system stabilizers in a relatively short phase of the violent correction inflation (affected by the change in the prices structure).

Actions against hyperinflation in the initial transformation stage focused on the adoption of the fixed currency rate of the Polish zloty (PLN) against the US dollar (USD) by the National Bank of Poland (from January 1990). The liberalization of the currency market proceeded along with the decrease of price dynamics and slow-down of the adjustment processes in the real sphere of the economy. The changeability of the currency prices has become dependent on the
market mechanisms to a higher degree. In the first step, a fixed currency rate was replaced by a basket of currencies with the structure close to the structure of payments in the foreign trade. At the same time the crawling peg system was adopted (from May 1991). In the next stage the reference rates (with broadening intervals of acceptable deviations) were introduced. Finally, in April 2000, the floating exchange rates replaced the previous solutions (see: Table 1).

(Table 1)

Results of the long-run analyses indicate that independently from the numerous changes in the currency system, the policy of the central bank in years 1992-2001 was uncontradictory with the currency parity conditions. Adoption of such hypothesis requires however incorporation of additional factors. In particular, the results of many investigations support the hypothesis about the significant influence of the interest rate arbitrage and the inflow of the capital for the foreign direct investments (FDI). Neglecting the latter may lead to the false conclusions about systematic overvaluation of the Polish zloty, when the relative prices of the tradable goods are assumed to be the benchmark (see: Kelm 2001, 2002).

However taking into account the “extended” currency rates parity hypothesis in the analysis of the ultra-short run horizon volatility would be justified only if it was known to all the participants of the currency market. In particular this would enable the approximation of the direction of changes in form of the market responses to its disequilibrium. Although similar reactions of the investors were observed in the 1990s (with the reference currency rate as a benchmark), the strictly short-term mechanisms decided in practice about the volatility of the nominal exchange rates. A dominant role should be assigned to the exchange rate
expectations connected with the changes of the central bank interest rates, inflow of the foreign currencies for the privatization processes and the changes in the domestic money supply resulting from sale of the treasury bills and government bonds issues. Equally important in this respect are speculative capital movements and constantly updated new information about the major macroeconomic indicators (mainly concerning the current account balance).

Formalization of the above-mentioned relationships within the econometric model is impossible due to the unavailability of appropriately disaggregated time series. Moreover, a limited access to the daily and intradaily data usually restricts the analysis of the causal relationships to a relatively small number of theoretical models.

Therefore the starting point for the investigation of the daily volatility of the Polish zloty currency rates follows the hypothesis of the covered interest rates parity\(^1\):

\[ s = f - i + i^* , \]  

where:

- \( s \) - spot exchange rate,
- \( f \) - forward exchange rate,
- \( i, i^* \) - domestic and foreign money market nominal interest rate.

In a short-term stochastic approximation of the above equation some additional explanatory variables were taken into account:

\[
\Delta s^{CO} = B_1(L)\Delta i + B_2(L)\Delta i^* + B_4(L)\Delta f \\
+ B_4(L)\Delta s^* + B_5(L)\Delta w + B_6(L)\Delta s^{OC} + B_7(L)\Delta s^{CO} + \xi_t ,
\]  

where:

\(^1\) Lower case letters stand for the natural logarithms.
$B_k(L)$ - polynomial lag operator,

$\Delta s^{CO}$, $\Delta s^{OC}$ - “close-to-open” and “open-to-close” growth rate of the spot exchange rate (USD or EUR),

$\Delta s^*$ - EUR/USD “close-to-close” exchange rate growth (price of 1 Euro in US dollars, appears in Euro equation only),

$\Delta w$ - growth rate of the WIG index (Warsaw Stock Exchange main index),

$\xi : IID(0, \sigma^2)$ and $k = 1, \ldots, 7, \ t = 1, 2, \ldots, T$.

According to this specification the effect of the capital flows between money and capital markets is represented by the changes of the Warsaw Stock Exchange main index WIG. On the other hand the inclusion of the EUR/USD volatility allows for the verification of the hypothesis that there occurred interventions of the central bank, which aimed at the attempts to stabilize the Polish zloty rate against other European currencies (mainly DM and later EUR). In case it is so – the argument about similar volatility of the Polish zloty against the European currencies could be used in the negotiation process before the accession of Poland to the European Union (EU) and later on to the European Monetary Union (EMU). Addition of the autoregressive factors targets at capturing the impact of the omitted variables on one hand and the quantification of the adjustment processes on the other.

4. Methodology

Financial market time series data usually feature a volatility clustering effect which – in case of traditional econometric models – is the direct cause of error term heteroscedasticity. Therefore the GARCH models (see: Engle 1982, Bollerslev 1986 and for the summary: Bollerslev et al. 1992 and Bollerslev et al.
1994) usually find a straightforward application as a tool for modeling and forecasting financial markets.

4a. GARCH models

A linear generalized autoregressive conditional heteroskedastic GARCH($S,Q$) model:

\[ r_t = x_{(k)} \alpha_{(k)} + \xi_t, \quad (3a) \]

\[ \xi_t = \vartheta_t h_t, \quad (3b) \]

\[ h_t = \gamma_0 + \sum_{s=1}^{S} \gamma_s \xi_{t-s}^2 + \sum_{q=1}^{Q} \phi_q h_{t-q} \quad (3c) \]

where \( \vartheta_t : \text{IID}(0,1) \), \( \xi_t : \text{IID}(0, \sigma_\xi^2) \),

\[ E(r_t) = E(r_t | r_{t-1}) = x_{(k)} \alpha_{(k)}, \quad (4a) \]

\[ D^2(r_t | r_{t-1}) = h_t, \quad (4b) \]

and \( r_t \) is the rate of return of the financial market instrument, \( x_{(k)} \) stands for the vector of explanatory variables and \( \alpha_{(k)} \) for the vector of the structural parameters, can be extended in two different directions. The first strategy takes into account an expansion of the conditional variance function \( h_t \) in (3c) to a more sophisticated specification aiming at a better description of the volatility of \( \xi_t \). The second approach is based on the assumption that the deterministic part in basic regression equation (3a) should incorporate the variables which have causal effects on the dependent variable. Obviously the best results should be delivered by the synthesis of those two views. Such a “combined” approach ensures that the model incorporates the existing causal relationships and, on the other hand, it guarantees the desired properties of the estimators.
The subject of analysis is the dependent variable $r_t$ in (3a) usually defined as a growth rate, $r_t = \ln y_t - \ln y_{t-1}$ and called return, where $y_t$ is the corresponding financial market price (i.e. currency price). The models are usually estimated by the maximum likelihood (ML) method.

4b. Direction quality measures for GARCH models

Traditional goodness of fit measures applied for the high frequency financial market data, defined as returns, very often constitute an imperfect criterion for the models evaluation. The $R^2$ values typically do not exceed a 0.1 level and the discrimination between models based on such criterion is very troublesome.

Recently some alternative measures have been proposed which rely on the relationship between the conditional variance function $h_t$ of the ARCH class model and the squared return $r_t^2$:

$$E(r_t^2 | \Psi_{t-1}) = E(\varepsilon_t^2 | \Psi_{t-1}) = h_t,$$  \hspace{1cm} (5)

where $\Psi_{t-1}$ is the set of information available at time $t-1$. For the properly specified model, the relation (5) leads to the conclusion that the goodness of fit measure for the GARCH model is the determination coefficient, $\bar{R}^2$, from the equation:

$$r_t^2 = \varphi_0 + \varphi_1 h_t + \xi_t,$$  \hspace{1cm} (6)

The description of those measures and their specific extensions taking advantage of the high frequency data can be found in: Andersen and Bollerslev (1998).

Another alternative measures proposed so far are based on the idea that in practice it is more important that the model’s forecasts properly reflect future
direction of changes rather than the model is characterized by a good fit. Such indicators are therefore especially useful in case of models based on the rates of return – where the direction of changes of the explained variable switched very frequently. The initial idea of those measures, called the direction quality measures, was introduced by Pesaran and Timmermann (1992).

The measure indicating the share of the properly captured change directions to the total number of observations in the sample is:

$$Q_1 = \frac{N\{r_i \hat{r}_i > 0\}}{N\{r_i \hat{r}_i \neq 0\}},$$  \quad (7)

where:

- $\hat{r}_i$ - theoretical values of the dependent variable,
- $N\{r_i \hat{r}_i > 0\}$ - number of observations for which $r_i \hat{r}_i > 0$,
- $N\{r_i \hat{r}_i \neq 0\}$ - number of observations for which $r_i \hat{r}_i \neq 0$.

It can be extended in the way that it shows the ability of the model to predict turning points:

$$Q_2 = \frac{N\{r_i \hat{r}_i > 0 \mid r_{i-1} r_i < 0\}}{N\{r_i \hat{r}_i \neq 0 \mid r_{i-1} r_i < 0\}},$$  \quad (8)

where $N\{r_i \hat{r}_i > 0 \mid r_{i-1} r_i < 0\}$ is the number of observations for which $r_i \hat{r}_i > 0$ under the condition that $r_{i-1} r_i < 0$. The above is a ratio of predicted turning points to the number of all turning points in the sample.

Both measures $Q_1$ and $Q_2$ take on the values from the 0 to 1 interval.

The total magnitude of predicted absolute changes to the sum of missed absolute changes in a given sample is measured by:

$$Q_3 = \frac{\sum_{i=1}^{T} |r_i|}{\sum_{i=1}^{T} |\hat{r}_i|},$$  \quad (9)
while for the average predicted and missed returns this measure takes the following form:

$$Q4 = \frac{\left(\sum_{t=1}^{T} |r_t^*| \right) / \text{N}(\{r_t^* > 0\})}{\left(\sum_{t=1}^{T} |r_t| \right) / \text{N}(\{r_t > 0\})}$$  \hspace{1cm} (10)

where:

$$r_t = \begin{cases} 0 & \text{for } r_t^* \leq 0 \\ r_t & \text{for } r_t^* > 0 \end{cases}$$

$$r_t^* = \begin{cases} 0 & \text{for } r_t^* > 0 \\ r_t & \text{for } r_t^* \leq 0 \end{cases}$$

For the well specified model both $Q3$ and $Q4$ should be greater than unity, however the higher their values the better the chance for a successful trading strategy formulation.

Transaction costs (for the currency market we assume between 0.1% and 0.5% per trade) imply that those measures should be ”filtered” to make such evaluations realistic. For a 0.1%-filter $Q1$ takes the form:

$$Q1_{(0.1\%)} = \frac{\text{N}(\{r_t^* > 0 \mid r_t > 0.1\%\})}{\text{N}(\{r_t^* \neq 0 \mid r_t > 0.1\%\})}$$  \hspace{1cm} (11)

The description of the direction quality measures can be found in: Welfe, Brzeszczyński (1999) and Brzeszczyński, Kelm (2002).

5. Empirical results

The database used in the presented investigation contains daily and intraday quotations and covers the period of over 6 years: from January 1996 to March 2002 (75 months). It includes major domestic and international currency rates (EUR/PLN, USD/PLN, EUR/USD and others), Polish money market interest
rates (WIBID/WIBOR) and international interest rates (LIBOR, EURIBOR on major international currencies), domestic forward currency rates (on EUR/PLN and USD/PLN) and international forward rates (on EUR/USD) - that is: ON, TN, SW, 2W, 3W, 1M, 3M, 6M, 9M and 1Y – as well as major international stock market indices. The primary data source is Reuters (Reuters Serwis Polski - RSP and Reuters Markets 3000).

The database was adjusted to take into account the non-trading days (such as weekends, holidays etc.) in Poland and abroad to make all the time series comparable.

According to the equation (2) the subject of analysis were the “close-to-open” (CO) exchange rates: EUR/PLN and USD/PLN (see: Figures 1 and 2). The choice of the CO definition of the explained variable has been motivated by the fact that in case of the investment strategies it is more important to predict the daily change (from the daily close to the daily open) rather than the “close-to-close” or “open-to-close” (from the previous day). Such forecasts possess straightforward application in the daily and intradaily spot and derivative trading strategies and therefore they are most interesting from the practical point of view.

The estimation of the model’s (2) parameters was conducted within the framework of the GARCH methodology in line with the strategy congruent with the “from-general-to-specific” (FGTS) approach. The search of the best model was conducted on two parallel levels: reduction of specifications of the basic regression equation (3a) and modifications of the conditional variance function (3c). The following steps were taken.

Firstly, due to the lack of good a priori information about which interest rates constitute the most important benchmark for the trading decisions of the investors, all the available LIBORs on USD and EUR as well as the domestic WIBORs on
PLN (from ON to 1Y) were considered. By analogy, the same approach has been adopted for the forward contracts with different dates (from TN to 1Y). Selection of the explanatory variables in the basic regression equation in all the models was conducted based on the values of the direction quality measures. The results allowed to obtain the best model’s specifications, which include WIBID 6M domestic money market interest rate, LIBOR 1Y interest rate on the EUR and USD and forwards 1Y on both EUR and USD. The estimation results for various types of GARCH class model (ARCH, GARCH, ARCH-M) have led to the conclusion that in almost all cases the GARCH(1,1) model proved significantly better than its alternatives.

Secondly, an important part of the investigation was the inclusion of some “exogenous” variables into the conditional variance function of the models – such as volume of trading, spread between high and low prices and others. The selection criterion in this case, as in the case of the zero-restrictions, was the precision of the estimates of the parameters connected with those additional variables. The results indicate that in case of the investigated phenomenon those modifications did not prove significantly better than the standard GARCH(1,1) model.

Thirdly, it was assumed that the adjustment processes horizon does not exceed 5 days. The zero-restrictions were imposed on the parameters, which estimators were characterized by high standard deviations.

Estimation of the parameters was conducted on the sample covering the period of 21.03.2000 – 8.03.2002 for the EUR/PLN and 14.08.2000 – 8.03.2002 for the USD/PLN currency rates. The reasons behind such choice are connected with the microstructure features of the Polish currency market. In particular they refer to the evolution of the exchange rate system: the freely changing exchange
rates (floating system) have been introduced only in April 2000 (see: Table 1). Thus we assume that all such analyses should be conducted starting from or even after this date.

In the end the following specifications of (3a) for EUR/PLN:

\[
\Delta s_{t}^{CO(EUR)} = \beta_{10}\Delta i_{t}^{WIBID6M} + \beta_{11}\Delta i_{t-1}^{WIBID6M} + \beta_{12}\Delta i_{t-2}^{WIBID6M} + \\
+ \beta_{23}\Delta i_{t-3}^{LIBOR} + \beta_{24}\Delta i_{t-4}^{LIBOR} + \beta_{25}\Delta i_{t-5}^{LIBOR} + \\
+ \beta_{30}\Delta f_{t}^{6M} + \beta_{31}\Delta f_{t-1}^{6M} + \beta_{32}\Delta f_{t-2}^{6M} + \\
+ \beta_{40}\Delta s_{t}^{*} + \\
+ \beta_{50}\Delta w_{t} + \\
+ \beta_{60}\Delta s_{t}^{OC(EUR)} + \beta_{61}\Delta s_{t-1}^{OC(EUR)} + \\
+ \beta_{71}\Delta s_{t-1}^{CO(EUR)} + \beta_{72}\Delta s_{t-2}^{CO(EUR)} + \beta_{73}\Delta s_{t-3}^{CO(EUR)} + \beta_{74}\Delta s_{t-4}^{CO(EUR)} + \xi_{t}
\]

(12)

and USD/PLN:

\[
\Delta s_{t}^{CO(USD)} = \beta_{10}\Delta i_{t}^{WIBID6M} + \beta_{11}\Delta i_{t-1}^{WIBID6M} + \beta_{12}\Delta i_{t-2}^{WIBID6M} + \beta_{13}\Delta i_{t-3}^{WIBID6M} + \\
+ \beta_{20}\Delta i_{t}^{LIBOR} + \\
+ \beta_{30}\Delta f_{t}^{6M} + \beta_{31}\Delta f_{t-1}^{6M} + \beta_{32}\Delta f_{t-2}^{6M} + \beta_{33}\Delta f_{t-3}^{6M} + \\
+ \beta_{60}\Delta s_{t}^{OC(USD)} + \beta_{61}\Delta s_{t-1}^{OC(USD)} + \\
+ \beta_{71}\Delta s_{t-1}^{CO(USD)} + \beta_{72}\Delta s_{t-2}^{CO(USD)} + \beta_{73}\Delta s_{t-3}^{CO(USD)} + \beta_{74}\Delta s_{t-4}^{CO(USD)} + \xi_{t}
\]

(13)

exchange rates were adopted.

The comparison of the estimation results (see: Table 2) shows significant differences between the mechanisms of the short-term volatility of both EUR/PLN and USD/PLN currencies.

(Table 2)

Firstly, the USD/PLN exchange rate fluctuations are to a large degree connected with the volatility of the domestic interest rates. Their joint impact is
over three times higher than in the case of the EUR/PLN (the sum of short-term elasticities equals to −0.380 and −0.120 respectively). The scale of the interest rate LIBOR effect is, however, comparable for those two currencies (0.072 and 0.107 respectively), which in both cases is significantly higher than for the domestic rates. This result may indicate that the investors assign different weights to the information coming from the domestic and much more stable foreign market, although - on the other hand - it can also result from lower volatility of the LIBOR rates.

Secondly, in spite of a similar time horizon the influence of the forward rates is also much stronger in case of the USD/PLN (the elasticities are: 0.475 and 0.254 respectively). At the same time the precision of the estimates is significantly higher.

Thirdly, the hypothesis about the attempts to stabilize the changeability of the EUR/PLN rate has been close to the empirical confirmation. The estimate concerning the relationship between the USD/PLN currency rate and the EUR/USD (at the −0.445 level) indicates that in case of the depreciation of the USD against the EUR, an appreciation of PLN against the USD is observed.

Fourthly, stable relationship between the currency and capital markets has been identified only in case of the USD/PLN rate. Lack of the analogous dependency between the volatility of WIG index and the EUR/PLN exchange rate cannot lead however to the univocal conclusion.

Fifthly, negative signs of the lagged estimates at the “open-to-close” and the “close-to-open” variables support the hypothesis about the existence of the respective adjustment processes.
It is also worthwhile to note that all the estimates of the GARCH(1,1) variables are highly significant, however their values for both currencies differ to a large extent (see: Table 2).

To evaluate the model’s performance the direction quality measures were applied. The results are presented for both models of EUR/PLN and USD/PLN currency rates in Table 3. (Table 3)

The measure $Q^1$ indicates that both models explain about 0.677 and 0.654 of the volatility of the respective currency rates$^2$. The turning points, as measured by $Q^2$, are captured at the 0.713 level for the EUR/PLN and at the 0.618 level for the USD/PLN rates. The measures adjusted by 0.1% filters also reached high values - with $Q^2_{(0.1\%)}$ equal to 0.719 and 0.617 for both currencies respectively. The results for the 0.5% filter remain high only for the measure $Q^2$ whereas the value of $Q^1$ decreases nearly by half comparing to the one without any filter. The results for the measures $Q^3$ and $Q^4$ indicate that for both currencies the sum of absolute rates of return when model successfully reflected the direction of change is more than three times higher than in cases when the model was missing the right direction. By analogy, the average rate of return is about 1.5 times higher than otherwise.

$^2$ The benchmark, as in case of the random walk model, for the direction quality measures $Q^1$ and $Q^2$ is 0.5.
6. Conclusions

The results obtained in the presented investigation allow for drawing the following conclusions.

Firstly, GARCH methodology proved very useful in the analysis of volatility of the EUR/PLN and USD/PLN exchange rates.

Secondly, the hypothesis about an impact of the domestic and international money market instruments on the domestic currency rates has found a strong support. The results indicate the existence of relationships postulated by the covered interest rate parity.

Thirdly, the existence of the relationship between the capital and currency market could not be confirmed in the presented research. The investigation for the longer data sample should therefore be more conclusive.

Fourthly, the investigated models are characterized by a high ex post forecasts performance as measured by the direction quality measures. However in many cases, the results are more satisfactory for the EUR/PLN rather than for the USD/PLN currency rate.
References


Table 1. Exchange rate system in Poland, 1990-2001.

<table>
<thead>
<tr>
<th>Date</th>
<th>Exchange Rate System</th>
<th>Monthly Rate of Depreciation</th>
<th>Interval of Acceptable Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01.1990</td>
<td>fixed exchange rate (with respect to US dollar)</td>
<td>0.0 %</td>
<td>+/- 0.0 %</td>
</tr>
<tr>
<td>16.05.1991</td>
<td>crawling peg</td>
<td>1.8 %</td>
<td></td>
</tr>
<tr>
<td>23.08.1993</td>
<td>(with respect to currency basket, weights: USD=0.45,</td>
<td>1.6 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM=0.35, GBP=0.10, FRF=0.05, CHF=0.05)</td>
<td>1.5 %</td>
<td>+/- 0.5 %</td>
</tr>
<tr>
<td>16.02.1995</td>
<td>FRF=0.05, CHF=0.05)</td>
<td>1.2 %</td>
<td>+/- 2.0 %</td>
</tr>
<tr>
<td>16.05.1995</td>
<td>crawling band</td>
<td>1.2 %</td>
<td>+/- 7.0 %</td>
</tr>
<tr>
<td>8.01.1996</td>
<td>(with respect to currency basket, weights: USD=0.45,</td>
<td>1.0 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DEM=0.35, GBP=0.10, FRF=0.05, CHF=0.05)</td>
<td>0.8 %</td>
<td></td>
</tr>
<tr>
<td>26.02.1998</td>
<td>or USD=0.45, EUR=0.55)</td>
<td>0.7 %</td>
<td>+/- 10.0 %</td>
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<tr>
<td>16.07.1998</td>
<td>FRF=0.05, CHF=0.05)</td>
<td>0.5 %</td>
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<tr>
<td>9.09.1998</td>
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<td>+/- 12.5 %</td>
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<td>28.10.1998</td>
<td></td>
<td>0.3 %</td>
<td>+/- 15.0 %</td>
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<td>15.03.1999</td>
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</tr>
<tr>
<td>12.04.2000</td>
<td>float</td>
<td>-</td>
<td>-</td>
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Table 2. GARCH(1,1) estimates of the EUR/PLN and USD/PLN currency rates models.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Lag</th>
<th>EUR/PLN</th>
<th>USD/PLN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>-0.053 (0.048)</td>
<td>-0.169 (0.059)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-0.022 (0.058)</td>
<td>-0.079 (0.041)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-0.051 (0.050)</td>
<td>-0.077 (0.049)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-</td>
<td>-0.055 (0.046)</td>
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<tr>
<td>Δi</td>
<td>0</td>
<td>-</td>
<td>0.072 (0.020)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.037 (0.036)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.035 (0.032)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.032 (0.029)</td>
<td>-</td>
</tr>
<tr>
<td>Δf</td>
<td>0</td>
<td>0.184 (0.014)</td>
<td>0.230 (0.019)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.047 (0.047)</td>
<td>0.085 (0.028)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.023 (0.020)</td>
<td>0.078 (0.027)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-</td>
<td>0.082 (0.024)</td>
</tr>
<tr>
<td>Δw</td>
<td>0</td>
<td>-</td>
<td>-0.445 (0.307)</td>
</tr>
<tr>
<td>Δs^c</td>
<td>0</td>
<td>-</td>
<td>-0.064 (0.021)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-0.481 (0.134)</td>
<td>-0.383 (0.162)</td>
</tr>
<tr>
<td>Δs^c</td>
<td>1</td>
<td>-0.179 (0.120)</td>
<td>-0.152 (0.147)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-0.159 (0.055)</td>
<td>-0.117 (0.069)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-0.071 (0.055)</td>
<td>-0.094 (0.052)</td>
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<tr>
<td></td>
<td>4</td>
<td>-0.028 (0.046)</td>
<td>-0.075 (0.055)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-0.093 (0.041)</td>
<td>-0.114 (0.047)</td>
</tr>
<tr>
<td>GARCH(1,1) estimates</td>
<td>Lag</td>
<td>EUR/PLN</td>
<td>USD/PLN</td>
</tr>
<tr>
<td>γ</td>
<td>0</td>
<td>0.099 (0.048)</td>
<td>0.145 (0.048)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.073 (0.033)</td>
<td>0.308 (0.085)</td>
</tr>
<tr>
<td>φ</td>
<td>1</td>
<td>0.706 (0.105)</td>
<td>0.265 (0.160)</td>
</tr>
</tbody>
</table>

(Standard errors in parentheses)
Table 3. Direction quality measures for GARCH(1,1) models of the EUR/PLN and USD/PLN currency rates.

<table>
<thead>
<tr>
<th>Direction quality measures</th>
<th>EUR/PLN</th>
<th>USD/PLN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^1$</td>
<td>0.677</td>
<td>0.654</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>0.713</td>
<td>0.618</td>
</tr>
<tr>
<td>Number of turning points</td>
<td>258</td>
<td>178</td>
</tr>
<tr>
<td>$Q^{1\text{(0.1%)} }$</td>
<td>0.611</td>
<td>0.590</td>
</tr>
<tr>
<td>$Q^{2\text{(0.1%)} }$</td>
<td>0.719</td>
<td>0.617</td>
</tr>
<tr>
<td>Number of turning points (for $r_i &gt; 0.1%$)</td>
<td>231</td>
<td>162</td>
</tr>
<tr>
<td>$Q^{1\text{(0.5%)} }$</td>
<td>0.350</td>
<td>0.317</td>
</tr>
<tr>
<td>$Q^{2\text{(0.5%)} }$</td>
<td>0.718</td>
<td>0.721</td>
</tr>
<tr>
<td>Number of turning points (for $r_i &gt; 0.5%$)</td>
<td>124</td>
<td>68</td>
</tr>
<tr>
<td>$Q^3$</td>
<td>3.076</td>
<td>3.088</td>
</tr>
<tr>
<td>$Q^4$</td>
<td>1.465</td>
<td>1.636</td>
</tr>
</tbody>
</table>
Figure 1. Growth rate of the EUR/PLN “close-to-open” exchange rate (21.03.2000 – 8.03.2002).

Figure 2. Growth rate of the USD/PLN “close-to-open” exchange rate (21.03.2000 – 8.03.2002).