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Maroje Lang • Davor Kunovac
Silvio Basač • Željka Štaudinger

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CROATIAN NATIONAL BANK

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Maroje Lang
maroje.lang@hnb.hr

Davor Kunovac
davor.kunovac@hnb.hr

Silvio Basač
silvio.basac@hnb.hr

Željka Štaudinger
zeljka.staudinger@hnb.hr

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Modelling of Currency outside Banks in Croatia

Maroje Lang, Davor Kunovac, Silvio Basač, Željka Štaudinger

Abstract

This paper describes two econometric models for the short-term projections of currency outside banks in Croatia. The first model is a simple regression model that captures weekly, monthly and annual periodical patterns, given a daily series of currency outside banks. The second model, together with deterministic seasonality assumes the ARIMA structure of the residuals. Both models outperform the existing forecasts done in the CNB.

JEL: C53, C22, C32

Keywords: daily forecast, liquidity management, time series models

Contents

1 Introduction

With the change of the use of monetary policy instruments in 2005 that gave a prominent role to open market operations (OMO), the need to strengthen the liquidity management framework of the Croatian National Bank (CNB) has arisen. In particular, it was necessary to modify and improve the existing daily liquidity forecast so that it provides information on expected demand and supply of bank reserves, which is needed for deciding the amounts of liquidity to be created by regular open market operations.

The main forecasting horizon of the daily liquidity forecast is one reserve requirement maintenance period, which starts on the second Wednesday of the current month and lasts until the second Tuesday of the following month (4 or 5 weeks). However, within each reserve maintenance period, the main refinancing operations are held on a weekly basis, so the horizon of up to five working days is the most relevant.

The daily liquidity forecast depends on the accuracy of its individual components. While some items are in the central bank's control, others are influenced by external factors outside its influence in the short run. Those autonomous items determine the autonomous change in demand and supply of bank reserves that the central bank needs to offset by its open market operations. Especially important are currency outside banks and government deposits in domestic currency, whose movements increase or decrease the amount of bank reserves (liquidity). Whereas the government deposit is the most unpredictable item in the liquidity forecast, currency outside banks shows clear periodic patterns. This facilitates forecasting the short-term movement of currency. Due to the importance of cash for the conduct of monetary policy, many central banks have developed similar econometric models for forecasting.[1]

The paper has the following structure: the second section describes the forecasted series of currency outside banks in Croatia. The expert knowledge-based method of forecasting currency outside banks together with time series models developed for the purpose of forecasting currency outside banks is described in the third section. The evaluation of the forecasts obtained by these models is described in the fourth section. The final section is the conclusion.

2 Properties of the Currency outside Banks Series

2.1 Definition

Currency outside banks comprises of all banknotes and coins in the national currency held by economic subjects (households, companies and non-residents).

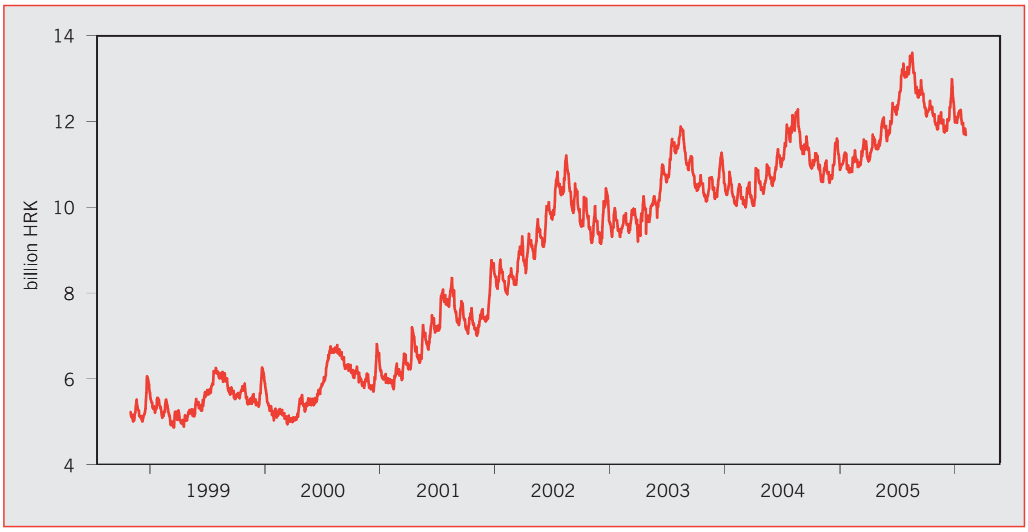
1 Among the models consulted in this paper are those of the European Central Bank (A. Cabrero et al. (2002)) and the Czech National Bank (Hlavaček et al. (2005)).

It includes all banknotes and coins of the national currency ever issued that are outside the banking system. When currency is returned to commercial banks, it is considered to be a part of the reserves of these banks with the CNB. Currency held by Hrvatska pošta (Croatian Post) and Fina[2] is treated similarly. Thus, currency outside banks is calculated as a difference between the total printed banknotes and coins and cash in the vaults of those involved in cash distribution:

	Total printed banknotes and coins of the national currency
–	Cash in the Croatian National Bank vaults
–	Cash in transport
–	Cash in Fina and Hrvatska pošta (Croatian Post) vaults
–	Cash in commercial banks vaults
=	**Currency outside banks**

The amount of currency in Fina usually reflects the increase or decrease of the cash held by households, i.e. the payments of salaries and pensions as well as the household consumption. The amount of currency in Hrvatska pošta indicates the payout of pensions in cash through the postal system. The payment of salaries and pensions has the strongest effect on the level of currency within a month (with the exception of the summer season and days before holiday seasons). The payment of pensions through the postal system is conducted in cash, and its amount does not depend on the recipient's preference to either keep the funds in a bank or withdraw it as cash. The calculation of currency outside banks therefore relies on information from a number of different institutions: commercial banks, Hrvatska pošta and Fina. Since they are all closed on weekends and public holidays, the data for currency outside banks is available only for working days. This brings some irregularity to the series (missing data for non-working days that creates some difficulties in applying the standard time series analysis, as described in Chapter 3).

Figure 1 Currency outside Banks in the Period November 1998 – January 2006



2 Financial Agency, the former Croatian clearing house, is the agency that distributes cash on behalf of the CNB.

Table 1 Basic Statistics of Currency outside Banks, in million HRK

	1999	2000	2001	2002	2003	2004	2005
Average	5498.4	5774.0	7021.8	9430.6	10361.7	10895.1	11960.7
Std. dev.	334.1	535.2	701.0	782.9	666.0	547.3	715.2
Max	6258.5	6803.3	8767.7	11198.7	11879.3	12279.8	13592.1
Min	4863.2	4939.2	5758.1	7967.0	9202.5	9994.3	10789.4
Beginning of the year	5588.4	5808.2	6247.6	8403.0	9605.8	10508.5	10872.7
End of the year	5827.1	6592.9	8507.4	9680.9	10573.1	10955.6	12307.1

2.2 Series Description

Figure 1 shows currency outside banks from November 1998 to January 2006. There is an increasing trend in currency during that period, which can be attributed to the growing demand for cash under conditions of economic growth. The positive impact of economic growth on currency is additionally emphasized by the stagnation of currency during the 1999 recession, and restoration of its growth from the second quarter of 2000, which coincides with economic recovery. Currency strongly increased at the end of 2001, when, before the introduction of euro banknotes, many Croatian citizens exchanged the banknotes of legacy currencies (DEM, ITL, ATS, etc.) into HRK banknotes, which resulted in an increase in domestic currency. The crisis in Riječka banka in early 2002 triggered a bank run and corresponding withdrawal of household savings from the banking system, which additionally increased the amount of currency outside banks. Since mid-2002, currency outside banks has exhibited a regular pattern with strong seasonality. The seasonality of the currency series can be seen in the pronounced maximums (peaks) and minimums (floors) and seasonal patterns that were identical in several years. The annual maximums of currency were reached in July and August, during the summer tourist season when tourist demand increases the holding of currency. Local maximums also take place at the end of December during Christmas shopping. The periods of high level of currency are followed by its decrease in September, and in January and February. Currency reaches its annual minimums in the period from January to April and in November to early December.

Regular patterns can also be identified within each month. Currency outside banks gradually increases from the fifth to (approximately) the fifteenth of the month, when salaries and pensions are paid out.[3] After that, currency decreases as households spend their salaries and pensions and there is no additional income in that period.

3 The government pays monthly salaries in an amount exceeding HRK 1bn, which is usually done by the 15th of the month. The monthly amount of pensions paid out through banks is an additional HRK 1bn, which is done between the 10th and the 12th of the month. The monthly amount of pensions paid out through the postal system is roughly HRK 500m, and is paid out between the 13th and the 15th of the month. The payment of salaries and pensions significantly increases the level of currency outside banks. However, uncertainty about the start of the payment of pensions was one of the largest problems when forecasting currency outside banks, and those payments were very frequently delayed in the past, so currency could not reach its maximum before the 19th or the 20th of the month.

Figure 2 Currency outside Banks on Mondays and Fridays in 2005

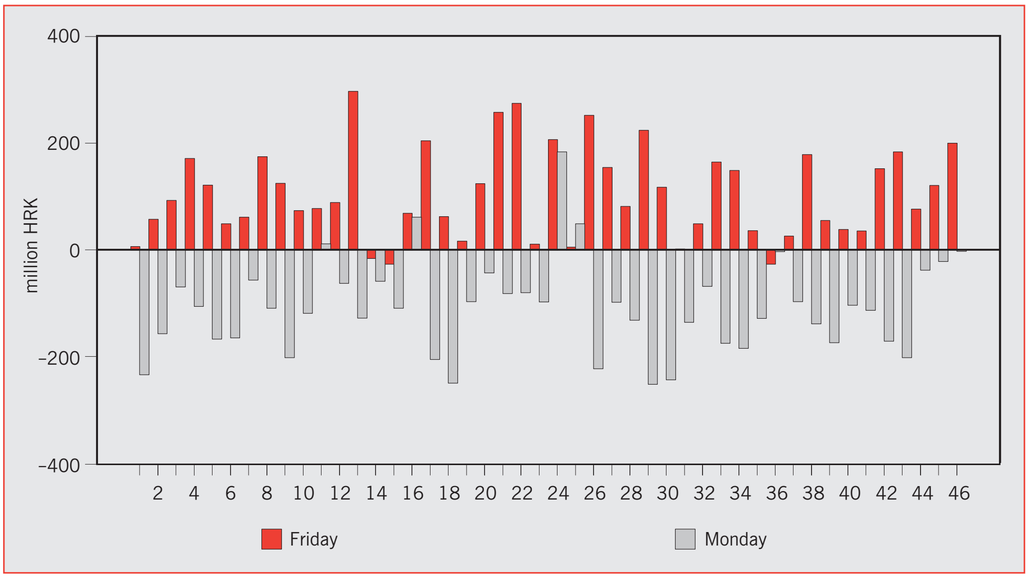
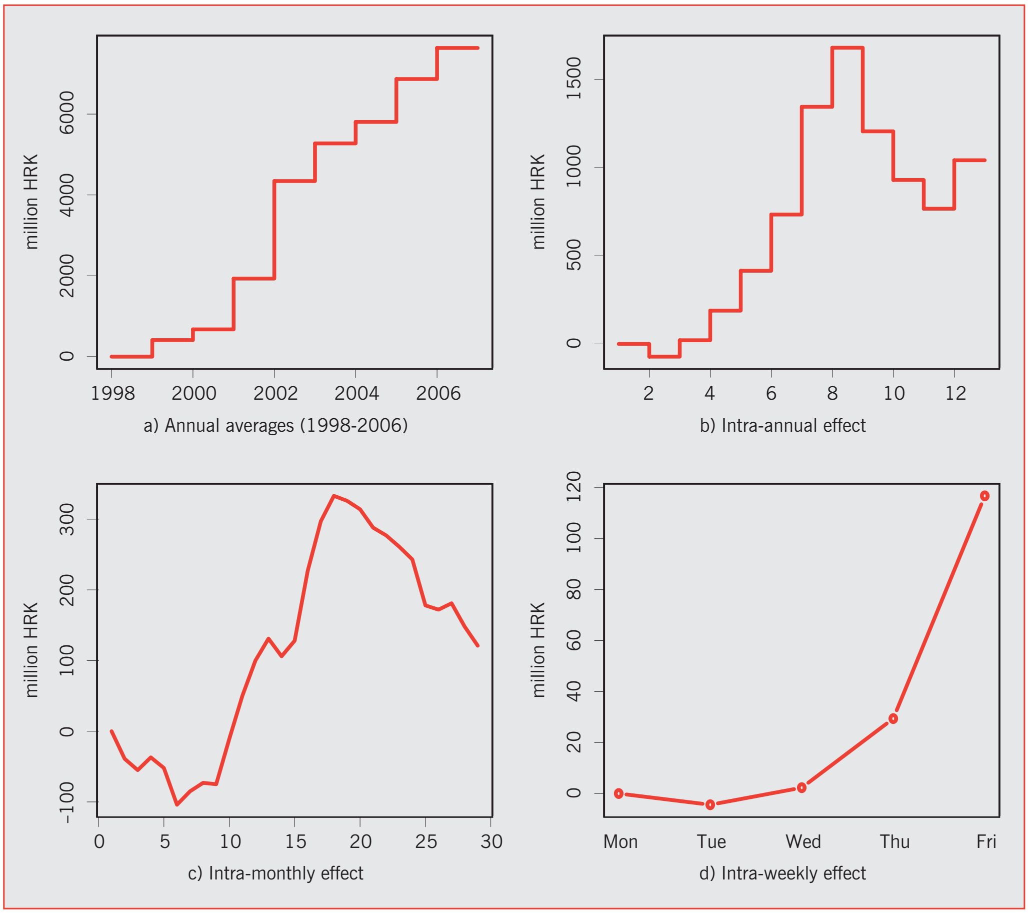


Figure 3 Periodic Patterns of Currency outside Banks



Note: Figure 3 a) provides the annual averages of currency outside banks. Figures 3 b), 3 c) and 3 d) show the effects of a particular month of the year, the day within the month and the day of the week on the total level of currency outside banks, presented as the deviation from January, the first day in the month and Monday, respectively. The method according to which the series has been divided into periodical components is analogous to the Regression model from Chapter 3.2, but is applied to the original (non-differenced) currency series.

As far as the intra-weekly pattern is concerned, currency in most cases increases on Fridays and decreases on Mondays. This is the result of household preference to withdraw cash for shopping over the weekend on Fridays. Currency outside banks decreases on Mondays when stores deposit the cash spent during weekends to Fina (which is closed on weekends). In the middle of the week seasonal factors are not as strong; however, the decreasing tendency is present on Tuesdays, and currency increases slightly on Thursdays. The intensity of the increase in currency over the weekend depends also on the position of the particular weekend within the month (currency increases most on the second and third weekends after the salaries and pensions are paid out).

3 Modelling of Currency outside Banks

The time series of currency outside banks with its regular patterns and the large number of observations is an ideal candidate for the application of the time series analysis for forecasting its future values. The time series analysis has been widely used in economic forecasting during the last twenty years, especially for forecasting the near future. Many central banks use similar models for forecasting their currency series.

Prior to this project, the CNB did not use a formal statistical model to forecast the daily series of currency outside banks, and forecasts were done by the CNB staff with expertise in understanding and forecasting currency outside banks (the process described in this paper as the Expert model). Therefore, the first step in the application of time series methods was to set up a simple model that resembles the existing process of making projections manually. This model (the Regression model – REG) describes the movement of currency outside banks in the form of a multiple linear regression using only deterministic explanatory variables. After that the standard ARIMA methodology was applied to develop the second model that consists of the regression model and the seasonal ARIMA model.[4] Both econometric models are to be used to forecast currency outside banks. In order to create accurate forecasts, it is necessary to formalize its annual, monthly and weekly patterns. In addition, we would like to model effects of holidays on currency holding. Finally, we eliminate the long-term (non-stationary) component by differencing the series.

3.1 The Expert Model

The Expert model is not a formal econometric model, but rather the set of rules used by the Liquidity Forecast Division when predicting daily series of currency outside banks. It is described here as we compared the forecasts of the estimated models with staff forecasts.

4 The ARIMA model for currency forecasting was developed by A. Cabrero et al. (2002), but here we have mostly followed the slightly modified version by Hlavaček et al. (2005).

The starting point in forecasting currency is its current level, and the forecasting horizon is one reserve maintenance period (4-5 weeks), while special attention is accorded to a week-ahead forecast, i.e. the duration of regular weekly reverse repos. When preparing a forecast, the extreme points are set first, taking into account tourist season expectations that raise the summer maximum, consumption during the Christmas shopping season and the payout of annual bonuses that increase the winter maximum, as well as information about increases in wages and pensions. The effect of the consumption increase before Easter is not quite as significant as during the aforementioned periods, especially since the cash outside banks is at the lower levels during the first few months of a given year.

The daily changes of the cash are forecasted on the basis of daily changes in the previous month of the current year and the daily changes in the same month of the last year. Short-term forecasts are updated on a daily basis using the monthly and weekly behavioural patterns exhibited in the past together with the most recent data (preliminary data of currency outside banks are available with a one day lag).

The combination of expert knowledge and historical data is used to assess the effects of holidays, where their position within a working week or month is also taken into account. Information about the major payments in the month are also taken into account: the payments of salaries in the public sector, payments of pensions through bank accounts and Hrvatska pošta (Croatian Post), and extraordinary payments, such as old savings, vacation bonuses and Christmas bonuses.

The described method produced accurate forecasts in the past. However, the models proposed below can facilitate and slightly improve the existing forecasting process.

3.2 The Regression Model of Currency outside Banks

The first econometric model, expressed in the first differences, has the following form:

$$\Delta y_t = \sum_{i=1}^{12} \alpha_i M_{it} + \sum_{i=1}^{4} \beta_i TD_{it} + d_t + \sum_{i=1}^{k} \Theta_i (B) \delta_{it} + \sum_{i=1}^{j} \gamma_i O_{it} + \varepsilon_t \qquad (1)$$

where y_t is the level of currency outside banks at time t, ε_t is the error term at time t, and deterministic variables M, TD, d, and O describe seasonal effects in the following manner:

Intra-weekly effect (TD) For each weekday i ($i = Mon,\ldots,Fri$) we define a dummy variable that at time t has a value 1 if i is the day at time t, or 0 otherwise:

$$TD_{it} = \begin{cases} 1, \text{ if day } i \text{ occurs at time } t \\ 0, \text{ otherwise.} \end{cases}$$

Monthly effect (M) In the model we assume that for each calendar month changes

5 This could be justified by assuming different linear trends within each month of non-differenced currency outside banks series.

of currency in circulation are stable, but on different levels.[5] According to that, for each calendar month i (i=*Jan,...,Dec*) we define:

$$M_{it} = \begin{cases} 1, \text{ if month } i \text{ occurs at time } t \\ 0, \text{ otherwise.} \end{cases}$$

Intra-monthly effect (d) Intra-monthly seasonality is conveniently defined as a linear combination of trigonometric functions:

$$d_t = \sum_{j=1}^{p} \left(a_j \sin \frac{2j\pi\, m_t}{M_t} + b_j \cos \frac{2j\pi\, m_t}{M_t} \right),$$

where m_t stands for the position of a current day (at time t) within a month and M_t is the total number of days of a current month. Parameter p is chosen arbitrarily and defines the number of different frequencies that we use in modelling the intra-monthly dynamics; however, they need to be used sparsely. Alternatively, the intra-monthly effect could be modelled with dummy variables for each day of the month (the total of 31 variables).

Holidays (δ_t) δ_i is the indicator function of holiday i:

$$\delta_{it} = \begin{cases} 1, \text{ if holiday } i \text{ occurs at time } t \\ 0, \text{ otherwise.} \end{cases}$$

$\Theta_i = \Theta_i(B)$ is polynomial[6] in variable B, where B is the standard backward shift operator. Term $\Theta_i(B)\delta_{it}$ should capture the change of the currency level before and after the holiday i.

Outliers In the analysis of the residuals, largest outliers are identified and their possible effect on other parameters is removed with dummy variables. Formally, if there is an unexplained high residual at time t, we define the following dummy variable:

$$O_{it} = \begin{cases} 1, \text{ if outlier } i \text{ occurs at time } t \\ 0, \text{ otherwise.} \end{cases}$$

We estimate regression coefficients α_i, β_i, a_i, b_i, γ_i, coefficients of the polynomial $\Theta_i(B)$ and residual variance. The estimation procedure was performed by applying the ordinary least squares estimator.

3.3 The ARIMA Model of Currency outside Banks

The second model we used has the following structure:

$$y_t = \sum_{i=1}^{4} \beta_i TD_{it} + d_t + \sum_{i=1}^{k} \Theta_i(B)\delta_{it} + \sum_{i=1}^{j} \gamma_i O_{it} + \eta_t, \tag{2}$$

6 In order to properly capture the effect around (before and after) holiday i, polynomial $\Theta_i(B)$ is allowed to contain both positive and negative exponents.

Regression variables are defined as in the previous model, but now we assume the ARIMA structure of residuals:

$$\eta_t = \frac{\theta(B)}{\phi(B)\delta(B)}\varepsilon_t,$$

where $\phi(B)$ and θ(B) are autoregressive and moving-average polynomials with all zeros outside the unit circle, and $\delta(B)$ is a difference polynomial (with all zeros just on the unit circle).

Model (2) consists of the regression and the ARIMA model, so this class of models is sometimes called regARIMA models. The deterministic component describes intra-weekly, intra-monthly and holiday effects, while the stochastic component describes the correlation structure of the series and describes the remaining periodicity (see Cabrero et al. (2002)).

In our analysis, the chosen ARIMA model must fulfil some standard criteria: the stability of parameters, good in-sample characteristics, the minimal autocorrelation of residuals, and, most importantly, the model needs to have good forecasting properties.

Analysing the sample from 1999 – 2004, we chose the following ARIMA polynomials in the model of the residuals:[7]

$$\delta(B) = \left(1 - B^{261}\right)(1 - B)$$
$$\phi(B) = 1 + \theta_1 B^6 + \theta_2 B^7 + \theta_3 B^{10} + \theta_4 B^{12} + \theta_5 B^{14} + \theta_6 B^{21} + \theta_7 B^{22} + \theta_8 B^{65}$$
$$\theta(B) = 1 - \phi_1 B^{261}$$

Bell and Hillmer (1983) suggested the following procedure for estimation of parameters in such models. First, by analyzing the autocorrelation function (ACF) and the function of partial autocorrelation (PACF) of residuals one can define the level of regular and possible seasonal differencing. After differencing the series, regression and ARIMA parameters are to be estimated simultaneously using the maximum likelihood method. Parameters can also be estimated using nonlinear least squares since they are asymptotically equivalent to the ML estimates. In this paper we used nonlinear least squares.

3.4 The Evaluation of Forecasts

The main purpose of the described models is to forecast the future values of currency outside banks, so it is important to evaluate their out-of-sample forecasts. For that purpose, the parameters of the models were estimated on the sample from August 2002 to December 2004. Their out-of-sample forecasts for 2005 are then compared with actuals. The procedure was such that both models were reestimated with each new observation, and forecasts were stored. The series of forecasts

7 The series of currency outside banks is available for working days only. Data for weekends and holidays are not available. In order to mitigate this problem only working days were used. The missing data for holidays that fell within a working week were constructed as an average of neighbouring working days. There are approximately 261 working days in a given year, so differencing at 261 lags removes the most of annual seasonality. 65 represents quarterly seasonality, and 21–22 monthly seasonality.

were then used to calculate the forecast errors in order to choose the best model.

The models described in the previous section, the Regression model (REG) and the ARIMA model (ARIMA), are compared with the Naive model (RW), which assumes no change in the level of currency in the future,[8] as well as with the staff forecasts created by the Liquidity Forecast Division of the CNB (Expert).

A standard evaluation of the statistics in Table 2 shows that both models (the Regression model and the ARIMA model) outperform the Naive (random walk) model, due to the strong seasonality of the series. However, the actual quality of the estimated models can best be assessed by comparison with the staff forecasts described in 3.1. It is important to emphasize that staff forecasts were based on preliminary data on currency outside banks, which is different from the final data. Thus the total error in the staff forecasts of currency outside banks includes both the standard forecast error and the difference between the preliminary and final series.[9]

Thus both statistical models (the Regression model and the ARIMA model) slightly outperformed the Expert model in 2005. Exceptionally, a day-ahead forecast with the ARIMA model has a slightly larger mean absolute error than the Expert model, but for longer forecasting horizons both statistics used for evaluating forecasting performance (MAE, RMSE) show that estimated models outperform the Expert model.

The results suggest that the Regression model (REG) gives the best short-term forecasts – up to 5 days ahead – while the ARIMA model outperforms it at longer horizons. However, forecasts are created on a large time interval (the entire year) and the model with the lowest forecasting error for the entire year does not necessarily create the best forecasts throughout all the subintervals of that year. When applying this model, it is important to examine in more details the forecasting performances of both models for each calendar month, around holidays, etc.

Consistent with the regular characteristics of projections based on autoregressive models, longer period ahead forecasts created by the ARIMA model have larger forecasting errors than on shorter term horizons. That is so because the forecasting error is being accumulated, i.e. a two-day-ahead forecast by definition includes a day-ahead forecast (and its error term). Similarly, a three-day-ahead forecast is being constructed based on the two-day-ahead forecast, and the same procedure is used when forecasting more distant future. This forecasting method is called chain forecasting and is standardly used in the autoregressive models (see Diebold (2004)).

Figure 4 shows the actual series of currency outside banks and its forecasts generated with the described models. Forecasts are very good for shorter horizons, while at horizons of twenty days (a maintenance period) the errors are more pronounced, especially during the summer months.

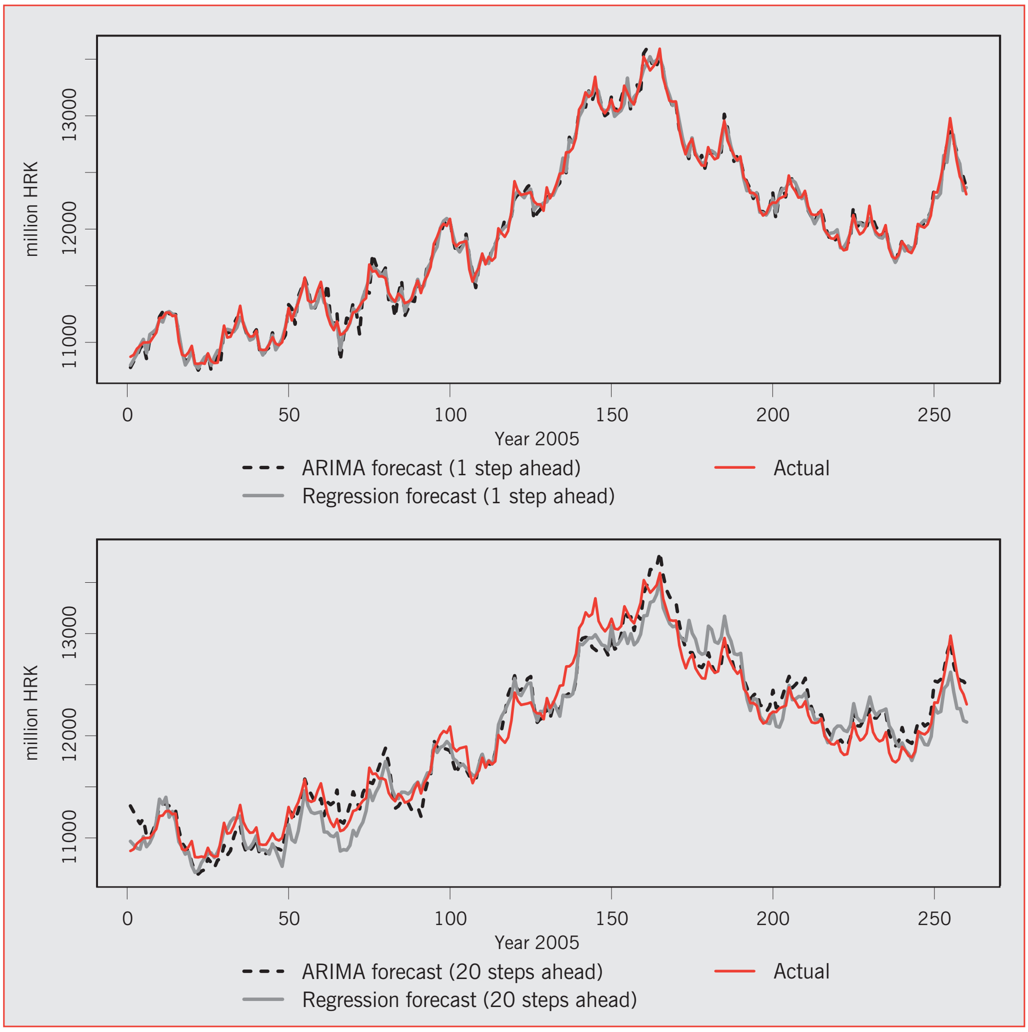
8 Here we assume simple random-walk structure of the currency outside banks: $y_t = y_{t-1} + \varepsilon_t$. So, h step ahead forecasts are computed as follows: $\hat{y}_{t+h} = E\left[y_{t+h} \middle| I_t\right] = E\left[y_t + \varepsilon_{t+1} + \ldots + \varepsilon_{t+h} \middle| I_t\right] = y_t$, where I_t is the information available at time t

9 See Appendix A.

Table 2 Mean Absolute Error (MAE), Percentage MAE (PMAE) and Root Mean Squared Error (RMSE) Statistics for Regression Model (REG), ARIMA Model (ARIMA), Official Model (Expert) and Random Walk Model

MAE (PMAE)					RMSE			
	REG	ARIMA	Expert	RW	REG	ARIMA	Expert	RW
1	44.7 (0.36%)	53.3 (0.45%)	52.6	80.9	56.9	70.5	70.8	106.4
2	62.9 (0.53%)	75.2 (0.63%)	79.4	123.7	79.9	95.2	102.6	157.0
3	73.9 (0.62%)	82.7 (0.70%)	/	153.7	94.5	106.5	/	191.3
4	82.1 (0.67%)	90.1 (0.76%)	/	176.6	103.3	116.2	/	216.0
5	89.3 (0.73%)	91.7 (0.77%)	117.4	199.1	113.7	118.5	160.7	239.6
6	95.6 (0.79%)	91.5 (0.77%)	/	229.1	122.7	118.5	/	281.7
7	100.9 (0.84%)	96.2 (0.81%)	/	254.9	129.3	122.9	/	314.1
8	106.8 (0.88%)	97.3 (0.82%)	/	275.1	134.4	123.2	/	336.7
9	112.5 (0.90%)	100.4 (0.84%)	/	286.7	139.9	127.4	/	351.3
10	119.1 (0.94%)	102.9 (0.86%)	/	299.7	146.5	133.4	/	365.9
15	124.0 (1.06%)	112.0 (0.93%)	/	318.9	157.0	140.0	/	407.8
20	137.9 (1.10%)	129.8 (1.08%)	/	359.5	167.8	154.7	/	430.8

Figure 4 Out of Sample Forecasts of Currency outside Banks with Different Horizons – 1 and 20 Steps Ahead



4 Conclusion

This paper describes two simple time series models for forecasting currency outside banks in Croatia. Both models produce good short-term forecasts, and outperformed the forecasts done by the CNB staff during 2005. The models complement each other in the sense that the first model, the Regression model based on the first differences, outperforms the second model, the ARIMA model, on the intervals up to 5 days ahead. On the other hand, the ARIMA model outperforms the Regression model at longer horizons. Due to differences in the approach of those two models, it is to be expected that there is a combination of forecasts that would outperform both models. This combination forecast might use different weights for each calendar month. The application of both models in regular liquidity forecasting framework should thus both improve and ease the production of daily forecasts of currency outside banks. The results should still be treated with caution and analysts who prepare the daily forecast need to evaluate the model forecast against the overall economic situation and adjust it for expected outliers in the series, such as one-time payments of debt to pensioners, etc.

An earlier version of the first model has been used by the Liquidity Forecast Division since June 2005 and initial experience has been positive. It was good with the forecasting horizon of up to 10 working days, although it failed to fully anticipate some sudden changes in the level of currency, especially during Easter 2006. The proposed models should improve the accuracy of the forecasts.

There are still a lot of improvements to be made in the daily forecasting framework of the CNB. On the one hand, a variety of more advanced forecasting methods such as neural networks (see Hlavaček et al. (2005)) could be employed. On the other hand, there are other variables (autonomous factors), such as cash in commercial bank vaults and government deposits whose forecasts can be further improved using the methods described in this paper.

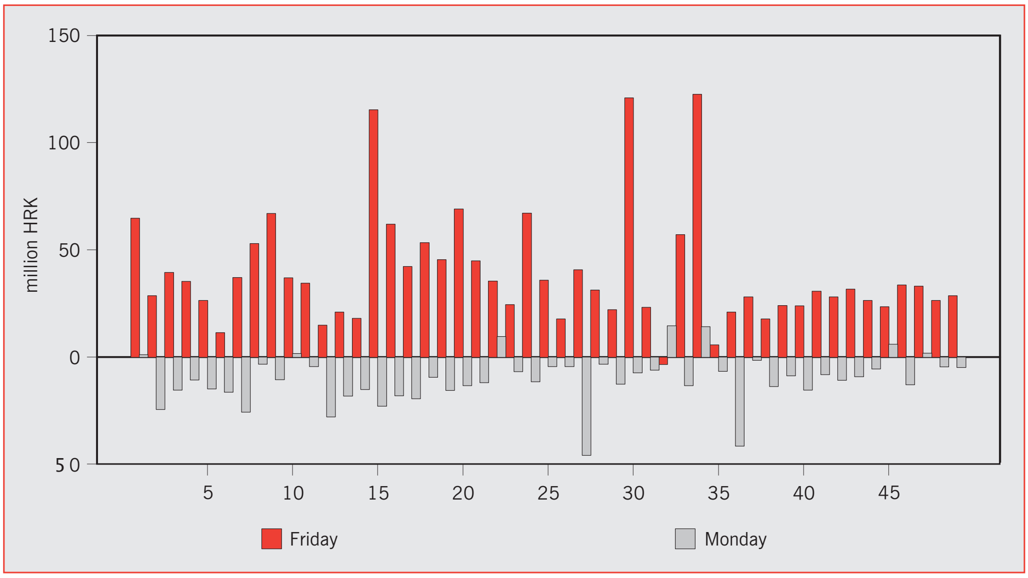
Appendix A

Difference between Preliminary and Final Data on Currency outside Banks

The daily short-term forecasts are done by using preliminary data on currency outside banks, which usually differs from the final series. The preliminary series is often corrected several times as the CNB receives more accurate information about cash in bank vaults and other items used when calculating currency outside banks. Thus, the forecast is done using an inaccurate data series.

If we could find some regularity in the difference between preliminary and final data, we could use it to improve the quality of preliminary values (adjust the series), which would, in turn, improve the quality of the forecast. Figure 5 presents the differences observed on Monday and Friday.

Figure 5 Difference between Preliminary and Final Series for 2005 – Monday and Friday



It is obvious that the difference between final and preliminary values is almost always negative on Monday and positive on Friday, which implies that the original data constantly underestimate the final level on Mondays and overestimate this value on Fridays. These regularities were not observed on other weekdays (Table 3).

Table 3 Statistics of Differences between Preliminary and Final Values per Day in 2005

	Mon	Tue	Wed	Thu	Fri
Median	–10.5	1.1	2.0	2.6	31.7
Mean	–10.3	2.8	0.4	3.9	38.7
Std. dev.	11.4	9.7	24.0	17.9	26.2

Table 4 Statistics of Differences between Preliminary and Final Values in 2005

	Difference				Absolute difference			
	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max
D1	7.1	25.2	–148.2	122.6	15.7	21.0	0	148.2
D2	3.4	21.2	–247.2	100.4	7.7	20.0	0	247.2
D3	0.8	19.3	–253.5	89.3	3.9	18.9	0	253.5
D4	0.3	18.4	–247.2	89.3	3.0	18.1	0	247.2
D5	1.1	8.7	–15.1	89.3	1.7	8.6	0	89.3
D6	1.2	8.6	–13.4	89.3	1.6	8.6	0	89.3
D7	1.2	8.5	–7.9	89.3	1.4	8.4	0	89.3
D8	1.0	8.5	–13.4	89.3	1.4	8.5	0	89.3
D9	1.1	8.5	–13.4	88.9	1.4	8.5	0	88.9
D10	1.0	8.4	–13.4	88.9	1.3	8.3	0	88.9

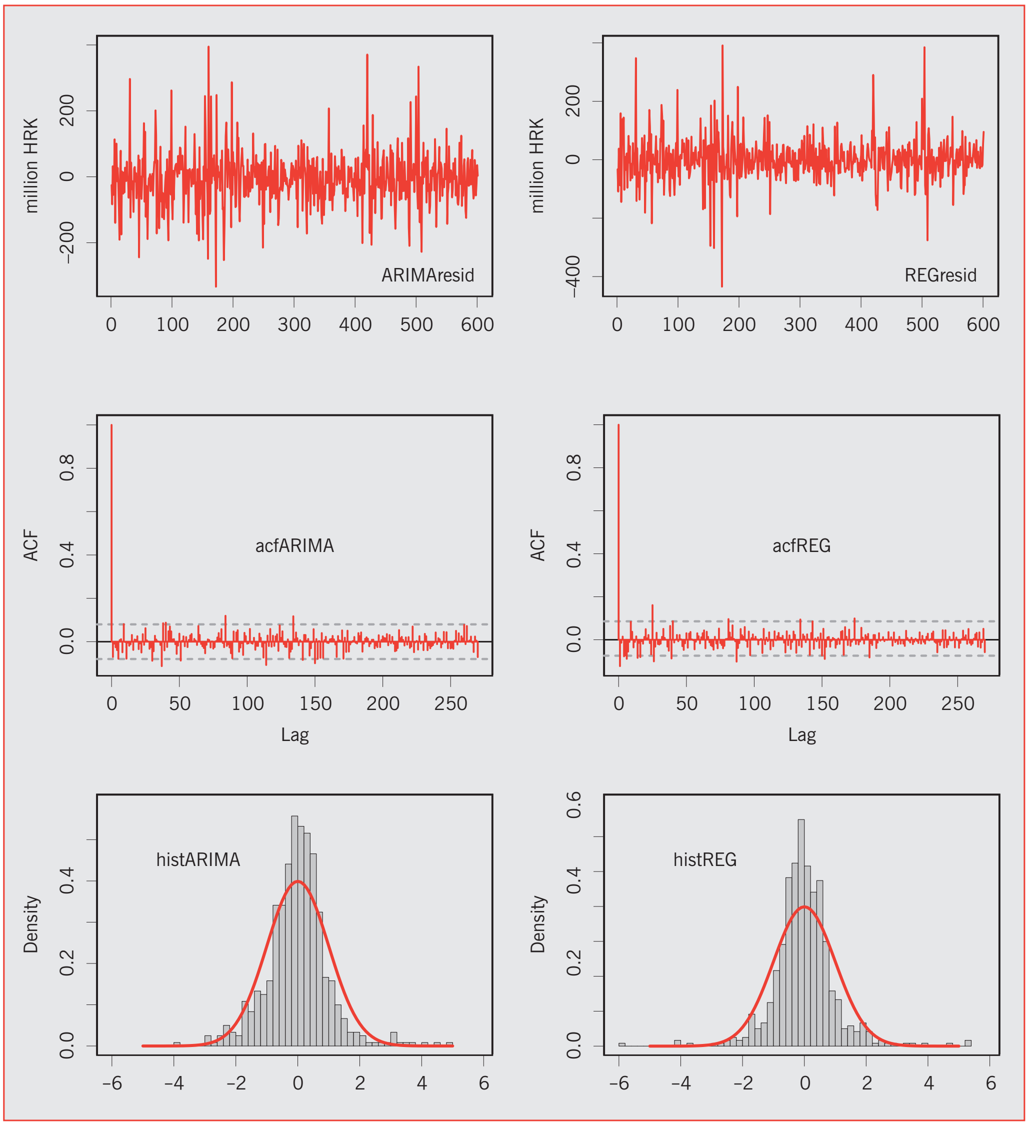
Table 4 provides statistics of differences and absolute differences of final series from the values received during the several subsequent days. The mark D1 refers to the difference between the final series and the originally received data, D2 to the difference between the final series and data received with a two day lag, etc.

Appendix B

Residual Analysis

Figure 6 shows in-sample residuals of both models. There are few outliers whose influence can be removed with dummy variables as described in 3.2. Histograms of standardized residuals of both models do not resemble the Gaussian density very well, but this can be somewhat corrected by a proper treatment of outliers. Sample autocorrelation functions suggest that there is still some autocorrelation left in the model so further whitening might also be achieved by including enough impulse dummy variables into the specification. The treatment of a possible ARCH effect is left for further research.

Figure 6 Residuals from the Estimated Statistical Models, Corresponding Sample Autocorrelation Functions



Note: The two bottom graphs illustrate the closeness of the standardised residuals to the standard normal density function.

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